TECHNOLOGY QUARTERLY.

PUBLISHED BY THE STUDENTS OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

VOL. I. MAY, 1888. No. 4.

THE BEGINNING OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

BY JAMES P. MUNROE, S.B.

IN an obscure corner of the Boston Daily *Advertiser* for Feb. 21, 1859, appears the condensed report of a meeting of "Individuals representing Associations of Agriculture, Horticulture, Art, Science, and various Industrial, Educational, and Moral Interests of the State," the results of whose deliberations were to be of far-reaching importance, and whose matured plans were to found an institution known throughout the civilized world. The account states that the meeting held in the library of the Boston Society of Natural History (then located on Mason Street), on Feb. 18, 1859, was attended by about forty gentlemen. Mr. Marshall P. Wilder was elected chairman, and Dr. Samuel Kneeland, Jr., secretary. After the formalities of organization, the chairman stated the object of the meeting to be that of taking steps toward memorializing the Legislature for a grant of land belonging to the Commonwealth, in aid of a plan for a conservatory of art and science. "The reading of a portion of the Governor's message* in which he refers

*Address of Gov. Nath'l P. Banks to Massachusetts Legislature, Jan. 7, 1859. [Acts and Resolves of Mass., 1859.] Referring to the Back Bay Lands, he says: — "The question of immediate interest is, what disposition to make of the proceeds of the sale of land which will bring to the treasury, within five years, at a moderate estimate, from three to five millions of dollars. . . . I trust the Legislature will be able to make provision

to the value of the public lands, and advises a certain disposition to be made of them, brought the matter fairly before the meeting."

Professor Agassiz, Hon. Alex. H. Rice, Mr. John D. Philbrick, and others spoke. While one of the gentlemen advocated the reservation of an open space of Back-Bay land, for the reason, chiefly, that the residents of Beacon Hill, heretofore cooled in summer by the breezes from the Back Bay, might not suffer by the filling in of that body of water, and although another of the speakers had so mean an idea of the enterprise as to urge the purchase of the Hancock estate, then on sale, the majority of those present were more serious in purpose and more generous in plan than these, and heartily indorsed the proposal for the reservation of a large tract of the still unfilled Back Bay. A committee of seven was appointed with power to memorialize the Legislature, in such manner as seemed desirable, for purposes of the proposed "Conservatory of Art, Science, and Historical Relics."

The committee thus commissioned lost no time in preparing and presenting their petition, for upon March 31, 1859, two days before the close of the session, the joint special committee of the Legislature appointed to investigate the matter presented their report* to that body. This report contains the memorial; and as the latter is the first definite exposition of the idea which had for so long been germinating in the minds of its promoters, it may be of interest to transcribe it with some fullness. Its main points are as follows: —

for the application of this property to such public educational improvements as will keep the name of the Commonwealth forever green in the memory of her children; and to this end I earnestly recommend . . . that the first public charge to be made upon this property shall be for the enlargement of the public-school fund until it net the sum of $3,000,000." Further on, he says: "The Secretary of the Board of Agriculture has commenced, and nearly completed, within the year past, a collection of specimens illustrative of the Natural History of the State. The idea, creditable alike in conception and execution, is suggestive of scientific enterprises of greater moment than a chance collection crowded into the vacant rooms of the capitol. Ought not Massachusetts, in the flush of wealth and power, to provide for the most complete illustration of her own natural history, or at least blend her efforts with the coöperative power of individuals, associations, and institutions, partially or altogether devoted to natural science, for the initiation of a work . . . [which] would enable her instructed people to trace the separate stages of existence through all mutations from nothing to Deity?" The collocation of scientific institutions and societies hinted at by the Governor was not an original idea with him, but he was the first, it is believed, to give voice publicly to this plan, long before conceived and advocated, in private, by a number of merchants and manufacturers, for promoting the growth of Massachusetts' arts and industries by concentrating and enlarging the existing means for scientific education and research.

* House Doc. No. 260, 1859.

"The undersigned . . . respectfully represent . . . that in our opinion a most effective method of making those lands" [belonging to the Commonwealth, lying near the Public Garden in the city of Boston] "available in promoting education, as well as directly developing the wealth of the State, would be for the Legislature to pass a Resolve reserving from sale a portion of said lands, and dedicating them as a space to be used in all coming time for the erection of a building or buildings by various institutions for public benefit, which in the aggregate would constitute and might be known as the Massachusetts Conservatory of Art and Science.

"The Committee, without undertaking to specify in detail the extent of space to be reserved or the specific purposes to which it should be dedicated, would simply suggest the character of a few leading institutions, which, if once established on the grounds, would form a nucleus around which would cluster kindred associations of immense value to the people of the State.

"Taking the Commissioners' Plan as a basis for illustration, we would suggest the reservation of as much as four squares for this purpose.

"Section No. I. might be devoted to collections of Implements, models, and other objects pertaining to Agriculture, Horticulture, and Pomology.

"Section No. II., to Natural History, Practical Geology, and Chemistry, with ample room for museums of specimens.

"Section No. III., to those institutions devoted to the development of Mechanics, Manufactures, and Commerce.

"Section No. IV., to Fine Arts, History, and Ethnology.

"The space reserved for each section should be ample for these and all institutions of a kindred character which the future progress of the State may develop. . . .

"It is not proposed to merge the different institutions in one,—the perfect individuality of each being retained in every respect, having nothing necessarily in common but the general fostering care of the State. . . .

"It is not proposed that the legal title to the land be conveyed, but the fee to remain to the State. . . .

"The Committee have reason to believe that there are now existing several well-established institutions which will avail themselves of the privilege under the reservation, if made, and will erect a building or buildings thereon for their respective uses as soon as the land can be put in readiness for occupation. . . .

"In conclusion, the Committee, while heartily sympathizing with the efforts now in progress to form a Museum of Natural History and Comparative Zoölogy under the auspices of Professor Agassiz, at Cambridge,* for the development of abstract science, desire to co-operate with such labors in the building up of institutions of a more directly practical

*Between 1859 and 1874, $355,707.67 was appropriated by the General Court of Massachusetts in aid of this institution.

character, which will enable the masses of the people engaged in industrial occupations more effectually to avail themselves of the advantages to be derived from the labors of those who are wholly devoted to purely scientific research."

This first exposition of the plans of its promoters shows their scheme to have been essentially a popular one. They hoped to educate the people,— to so train artisans and mechanics, that the relations between them and the men of science might be made more close; that the theory of the latter might be verified and checked by the work of the former, who, in their turn, should derive incalculable benefit from the experiments and researches of the scientists. Popular lectures, skillfully arranged museums, published reports of scientific research, were to be the means for education, and examinations and other tests leading to diplomas, were to form the immediate aim and measure of the work.

The Legislative Committee, in transmitting the memorial to the General Court, take it up point by point, enlarging upon and emphasizing the several details. They say: " . . . The objects contemplated in the memorial under consideration assume a position of great importance as an educational measure, and in the opinion of your Committee the plan, considered merely as a financial measure, should not be regarded with indifference by the State. Her future industrial progress will be greatly influenced by the practical educational facilities which these institutions, by their union, are designed to afford. The existence of such grand, practical schools in Europe requires of us to take all possible advantage of our resources in this direction, under the penalty of taking a second-rate position among the nations; and this no true American will be content to do without a struggle for the supremacy." After enlarging upon the educational advantages of the scheme proposed, after pointing out the benefits accruing to the State, to its people and industries, by such exhibitions and lectures as the plan of the memorialists contemplates, the committee consider the practical side of the question, the material advantage to the State, in the following words: —

"The Committee will venture an opinion, proved by all experience, that the surest way of increasing the value of unoccupied land, is to leave open spaces for public buildings like those proposed in this plan. The very fact of the location of these structures there would bring the land more rapidly into the market at increased prices, and secure a first-class population from the beginning. Unless some such plan be adopted, few persons would be likely to purchase except in the immediate vicinity of the Public Garden.

"The Committee are of the decided opinion that the reservation from sale of the land asked for in this memorial, will tend greatly to enhance the value of the remaining lands; and in their judgment this increase will equal the sum which the State would receive from the sale of the reserved portion. . . .

"Ample space is necessary in the beginning, in order that the various associations disposed to profit by it be neither crowded nor amalgamated. Space is the more important, as it is desirable that every county in the State should there have a space for the display of its products in every department of industry. . . .

"The land should remain open for some years, to allow associations, industrial and commercial, yet unformed, to avail themselves of the reservation.

"Finally, your Committee, would state, that as the societies are ready to unite, so are the people apparently prepared and eager for such an association of institutions as would be established by their union. This practical age demands practical, as well as theoretical, education. . . . And your Committee are of the opinion that the reservation of the land . . . should be made, believing it will be of advantage to the State, both in an educational and financial point of view.

"The Committee, however, notwithstanding an entire unanimity in these views, are united in the feeling that the present is not a propitious time for action in the premises, and therefore request to be discharged from the further consideration of the subject."

The unpropitiousness of the time had reference to the lateness in the session, and to the fact that many important bills were, as usual, being rushed through, and would inevitably push this petition to the wall. Upon the very day of the presentation of this report was passed the educational bill of 1859,* authorizing the reservation of one half the net proceeds from the sale of the Back Bay lands belonging to the State, after payment of $300,000 worth of scrip issued in 1856, to be divided as follows: To the school fund, 50 per cent; to the Museum of Comparative Zoölogy, 20 per cent; to Tufts College, 12 per cent; to Wesleyan Academy, Amherst College, and Williams College, 6 per cent each; provided that when the Museum shall have received $100,000, and the others in like proportion, the rest should go to the school fund. The only conditions laid down in this grant were, that the institutions should raise an amount equal to the State grant, by private subscription, and that Tufts, Williams, and Amherst Colleges should each maintain three free scholarships.

Notwithstanding the obvious inexpediency of legislation under such circumstances, an impression seems to have prevailed that this scheme for the promotion of popular scientific education had utterly collapsed.

*Chap. 154, Sec. 3, Acts and Resolves of 1859.

Appended to a printed copy of the memorial, accompanied by the Legislative Committee's report and issued by the memorialists, is found the following statement: —

"The Committee are desirous of correcting a false impression, which seems to prevail, that the plan has failed, and will state, in explanation, that it was in their opinion inexpedient to press so important a subject at the close of the session, especially as, if favorable action had been taken, the land would not be ready for occupancy this year. The committee did not expect definite action during the last session, and feel satisfied with the progress made, confident that in the ensuing year they shall be able to present an array of facts and arguments to the next Legislature that shall secure the establishment of these much needed educational institutions." (*Signed.*) Marshall P. Wilder, Geo. W. Pratt, Sam'l H. Gookin, Alfred Ordway, M. D. Ross, Alex. H. Rice, E. S. Tobey, James M. Beebe, Prof. Wm. B. Rogers, Dr. S. Cabot, Jr., Amos Binney, Dr. S. Kneeland, Jr., Chas. L. Flint, B. S. Rotch, J. D. Philbrick, *Committee.*

In this list, much enlarged from that appointed at the first meeting in the Rooms of the Natural History Society, appears for the first time the name of Professor Rogers, without whose controlling mind, inexhaustible patience, and undying enthusiasm, the Institute of Technology, zealous as were its other supporters, might never have been, and certainly could not have passed with safety through the dark days in store for it.

William Barton Rogers, son of Dr. Patrick Kerr Rogers, Professor of Chemistry and Physics at William and Mary College, was born, Dec. 7, 1804, at Philadelphia, being the second of four brothers, all of whom were afterwards distinguished for scientific attainment. At the age of twenty-four, his father having died, Wm. Rogers succeeded to the professorship, leaving it only to accept the chair of Natural Philosophy and Geology at the University of Virginia. To the duties of this distinguished position were immediately added those of State Geologist, to which office he was appointed by the Legislature of Virginia. The immense labor of making the survey of his adopted State, extending over seven years (1835–1842), in no degree abated his enthusiasm in his professorship. Fervent in imagination, though never unfaithful to the absolute truth of nature, gifted with eloquence extraordinary in itself, and doubly so in a student of the exact sciences, he could hold the most indifferent audience spell-bound with the magic of his expositions. His students at the University of Virginia gave no perfunctory attention; they listened because they could not help it. He not only forced them, by his marvelously clear and virile presenta-

tions of scientific facts and theories, to give strictest heed to him, but he aroused for the study itself an enthusiasm which did not die with the sound of his voice. He animated the cold marble of science, kindling a life-spark which no subsequent neglect could wholly extinguish.

Much of his work was done in conjunction with one or the other of his brothers, Henry D. and Robert E. Rogers. The power of joint investigation and publication exhibited in the work of these three minds, each endowed in so unusual a degree, is not the least remarkable fact in the history of this gifted family.

In 1849, Professor Rogers married Miss Emma Savage, daughter of Dr. James Savage, of Boston; and largely because of this union, he, in 1853, resigned his Professorship at the University of Virginia, and took up his residence in the city for which, in the thirty years of his life there, he was to do so much.

In the period between his coming to Boston and 1859, when the Conservatory of Art and Science was first publicly proposed, Professor Rogers was active in writing and lecturing upon scientific subjects. Although his comprehensive mind interested itself in all branches of science, his attention at this time was especially turned toward Physics, to the study of which he applied himself with his wonted enthusiasm. Doubtless, too, throughout these six years, he was sowing seed in the good ground of the enlightened understanding of Boston's merchants and manufacturers — seed which was to be tended and watched over by him far beyond the limit of his physical endurance, and the full vigor and promise, if not indeed the perfect fruition, of which he lived long enough to see.

Fortunate in the alliance of his thorough scholarship, patient enthusiasm, and extraordinary personal power, but impelled no less by their own zeal than by that of Professor Rogers, the committee named above, with additional members, presented a new memorial* at the next session of the Legislature. This, which met no better fate than the first, was essentially a repetition of it, somewhat more extended, and containing minor changes. To quote the petition:—

"In conclusion, your memorialists would remark that, although the present application coincides in its general purport with the memorial (House Doc. 260) which they had the honor to submit to the General Court last winter, it embodies the more mature results of the inquiries and deliberations in which they have since been zealously engaged."

Petitions in aid of this second memorial were presented by the Boston Society of Natural History, the Boston Board of Trade, the American

*House Doc. 13, January, 1860.

Academy of Arts and Sciences, the Massachusetts Charitable Mechanic Association, and the New England Society; the endorsement of each of these distinguished bodies, representing such diverse interests, being most cordial and hearty. A favorable bill was presented, and passed the House, but was, late in the session, rejected in the Senate. Upon motion to reconsider the vote of rejection, the bill was laid upon the table.

Although many meetings, more or less formal in character, of the "Committee of Associated Institutions of Science and Art," as it was now called, must have taken place during the winter of 1859–60, no record is known to exist of them, the only memorandum of the busy but silent work done at that time in furtherance of the scheme, being found in a pamphlet published in 1861,* in which the statement is made that,

"Believing that the failure of their previous appeal to the Legislature was, in part at least, due to the incompleteness and vagueness in which they had presented this department of their general plan" [Practical Instruction in the Arts and Applied Sciences], . . . "the Committee determined on taking such steps as were practicable toward the organization, in a preliminary form, of an institution of this character.

"Accordingly, at a meeting held May 28, 1860, the Committee assigned to a sub-committee, consisting of W. B. Rogers, E. B. Bigelow, J. M. Beebe, M. D. Ross, and C. H. Dalton, the duty of preparing and reporting the plan of an institution designed for the advancement of the Industrial Arts and Sciences and Practical Education in the Commonwealth."

Four months later, the sub-committee, through its chairman, issued a call for a public meeting to be held at the rooms of the Board of Trade, on October 5, 1860, and at this meeting was read the report of the Committee, outlining the plan of the Institute of Technology. The Conservatory of Arts and Sciences, with its huge collections, supplemented by instruction, is found to have given place to a school, in which the instruction is to be first, and the collections secondary, supplementary to the theoretical and practical teaching.

The pamphlet† is so clear in its exposition of the objects contemplated, its authors are so thoroughly master of the ideas and projects therein contained, that it is a temptation to transcribe it entire. A rough sketch must, however, suffice.

*An Account of the Proceedings Preliminary to the Organization of the Mass. Institute of Technology. Pph., 8vo., pp. 23. Boston, 1861.

†Objects and plan of an Institute of Technology [Prepared by direction of the Committee of Associated Institutions of Science and Arts, and addressed to Manufacturers, Merchants, Mechanics, Agriculturists, and other friends of enlightened industry in the Commonwealth]. Pph., 8vo, pp. 29. Boston, 1860; 2d ed., 1861.

After reciting the benefits to be derived from institutions of the nature contemplated, especially in a community like Massachusetts, largely devoted as it is to manufactures, it says: —

"With the view of securing the great industrial and educational benefits above alluded to, it is proposed to establish, on a comprehensive plan, an institution devoted to the practical arts and sciences, to be called the Massachusetts Institute of Technology, having the triple organization of a Society of Arts, a Museum or Conservatory of Arts, and a School of Industrial Science and Art."

It then states, at some length, the duties of the several committees, the sub-divisions of the collections, and the departments of the school. The organization may be summarized as follows: —

- Society of Arts.
  - Standing Committees of Arts.
    - On Mineral Materials.
    - On Organic Materials.
    - On Tools and Instruments.
    - On Machinery and Motive Powers.
    - On Textile Manufactures.
    - On Manufactures of Wood, Leather, Paper, India Rubber, etc.
    - On Manufactures of Pottery, Glass, and Precious Metals.
    - On Chemical Products and Processes.
    - On Household Economy, including Warming, Illumination, Water Supply, Ventilation, and the Preparation and Preservation of Food.
    - On Engineering and Architecture.
    - On Commerce, Navigation, and Inland Transport.
    - On the Graphic and Fine Arts.
- Museum of Industrial Art and Science, or Conservatory of Arts.
  - Standing Committee on the Museum.
    - To have charge of Collections arranged on the plan indicated by sub-divisions of Committees of Arts.
- School of Industrial Science and Art.
  - Standing Committee on the Schools.
    - School of Design.
    - School of Mathematics (elementary and applied).
    - School of Physics (general and applied).
    - School of Chemistry.
    - School of Geology
      - Physical Geology.
      - Mining.
- Standing Committee on Publications.
  - To have direction of the Printing of the Proceedings and Memoirs of the Institute, and of the publication of the "Journal of Industrial Art and Science."

The development of the Society of Arts and the School of Industrial Science is sufficiently well known. The Museum of Arts needs but money and space to become an accomplished fact. The Journal, which the Committees contemplated, "besides setting forth the proceedings of the Society, and the condition and progress of the Museum and School of Industrial Science, should furnish a faithful record of the advance of the Arts and Practical Sciences at home and abroad," has never been started, for the reason perhaps, that, the first two objects are attained by the "Proceedings of the Society of Arts" and the Catalogues and President's Reports published annually, while the third aim is amply met by the multifarious scientific journals and reports continually brought forward. In relation to the School, the Report says: —

"In arranging the plan and courses of instruction, provision would be made for the two classes of persons for whose benefit they are designed,— those who enter the school with the view of a progressive systematic training in applied science, and who have the preliminary knowledge, as well as time, for a continuous prosecution of its studies; and the far more numerous class, who may be expected to resort to its lecture-rooms for such useful knowledge of scientific principles as they aan acquire without methodical study, and in hours not occupied by cctive labor.

"The former would of necessity be subjected to classification and direction in their studies, as well as examinations and other tests of acquirement in the progress and at the close of their terms. The latter, without having access to the exercises of the class-room, would be admitted to the courses of lectures on general and applied science, subject only to the conditions and restraints that are usual in public lectures generally." . . .

"In regard to the latter feature of the School we may remark, that as the system of merely popular lecturing in its usual form would be inconsistent with the grave practical purposes which we have in view, it could not be recognized in connection with our plan." . . .

"In the features of the plan here sketched, it will be apparant that the education which we seek to provide, although eminently practical in its aims, has no affinity with that instruction in mere *empirical routine* which has sometimes been vaunted as the proper education for the industrial classes. We believe, on the contrary, that the most truly practical education, even in an industrial point of view, is one ounded on a thorough knowledge of scientific laws and principles, and which unites with habits of close observation and exact reasoning a large general cultivation. We believe that the highest grade of scientific culture would not be too high as a preparation for the labors of the mechanic and manufacturer. . . .

"But such complete and comprehensive training can, in the nature of things, be accessible to only comparatively few; while the limited and special education which our plan proposes would, we hope, fall within the reach of a large number whom the scantiness of time, means, and opportunity would exclude from the great seats of classical and scientific education in the Commonwealth."

"It will thus be seen, from the peculiar character and objects of this Department of the Institute, that it could not interfere with the interests of the established schools of learning devoted to general literary and scientific education."

The "Object and Plan" was distributed widely through the State of Massachusetts, accompanied by a circular asking the attention and co-operation of those receiving it. Two months later followed another circular, announcing a meeting to be held in Mecantile Hall, 16 Summer Street, on the evening of Jan. 11, 1861, "for the purpose of adopting measures preliminary to the organization of the Institute, and in furtherance of a petition to the Legislature for a charter, and a portion of the Back Bay lands."

This meeting was largely attended, addresses being delivered by Prof. Benjamin Peirce, the Rev. Dr. Gannett, and others, and formal resolutions were passed associating the subscribers for the purpose of endeavoring to organize and establish "The Massachusetts Institute of Technology," and appointing a committee of twenty to act in co-operation with the Committee of Associated Institutions of Science and Arts, to promote the incorporation of the Massachusetts Institute of Technology, and frame a constitution and by-laws for the government of the said Institute when it shall be established.

The third memorial was, in January, 1861, properly presented to the General Court, and by them referred to a Joint Standing Committee of the Legislature. This Committee made, on March 19, 1861, a report* entirely favorable to the grant, ". . . Believing the objects of this Institution to be of the highest moment to the material and educational progress of the State," . . . "and believing that the public advantages contemplated in the plans proposed would be wisely purchased by a share of the direct bounty of the Commonwealth."

"Such, however," the report of the Committee goes on to say, "is not the kind of aid craved by the petitioners. The land for which they apply has already indirectly and in part, at least, been dedicated to public education. They do not propose to withdraw it from this object, but, on the contrary, to give it a new and vastly increased value for

*House Doc. 171, 1861.

educational purposes," . . . "and your Committee are in favor of granting the prayer of the memorialists to the extent and according to the conditions of the following bill." Then follows the Act of Incorporation.*

The report of the Committee being accepted in the House, we find that on March 21st the bill proposed was passed to a third reading by a vote of 89 to 33. On the next day a motion to reconsider was made, but did not prevail, and upon the 25th the bill, with the addition of sections 9 and 10, as amendments, was, by the House, ordered to be engrossed; and upon the 29th the same action was taken by the Senate.

Upon April 10, 1861, more than two years after the subject was first publicly agitated, two years of almost constant effort in the face of opposition and discouragement, at an hour when the thoughts of the people were turned more toward impending war than in the direction of measures pre-supposing conditions of domestic peace and well-being, was legally established, by the approving signature of John A. Andrew, Governor of the Commonwealth, the Massachusetts Institute of Technology, in the terms of the following: —

Act† to incorporate the Massachusetts Institute of Technology, and to grant aid to said Institute, and to the Boston Society of Natural History.

Be it enacted by the Senate and House of Representatives, in General Court assembled, and by the authority of the same, as follows:—

SECTION 1. William B. Rogers, James M. Beebe, E. S. Tobey, S. H. Gookin, E. B. Bigelow, M. D. Ross, J. D. Philbrick, F. H. Storer, J. D. Runkle, C. H. Dalton, J. B. Francis, J. C. Hoadley, M. P. Wilder, C. L. Flint, Thomas Rice, John Chase, J. P. Robinson, F. W. Lincoln, Jr., Thomas Aspinwall, J. A. Dupee, E. C. Cabot, their associates and successors, are hereby made a body corporate, by the name of the Massachusetts Institute of Technology, for the purpose of instituting and maintaining a society of arts, a museum of arts, and a school of industrial science, and aiding generally, by suitable means, the advancement, development, and practical application of science in connection with arts, agriculture, manufactures, and commerce; with all the powers and privileges, and subject to all the duties, restrictions and liabilities, set forth in the sixty-eighth chapter of the General Statutes.

SEC. 2. [Relates to holding of estate.]

SEC. 3. [Specifies the lot of land to be reserved.]

*Section 1–8 only, see p.

†Chap. 183, Acts and Resolves of 1861.

SEC. 4. If at any time within one year after the passage of this act, the said Institute of Technology shall furnish satisfactory evidence to the Governor and Council that it is duly organized under the aforesaid charter, and has funds subscribed or otherwise guaranteed, for the prosecution of its objects, to an amount at least of one hundred thousand dollars, it shall be entitled to a perpetual right to hold, occupy, and control, for the purposes hereinbefore mentioned, the westerly portion of said second square, to the extent of two third parts thereof, free of rent or charge by the Commonwealth, subject, nevertheless, to the following stipulations, namely: persons from all parts of the Commonwealth shall be alike eligible as members of said Institute, or as pupils for its instruction, and its museum or conservatory of arts, at all reasonable times, and under reasonable regulations, shall be open to the public; and within two years from the time when said land is placed at its disposal for occupation, filled and graded, said Institute shall erect and complete a building suitable to its said purposes, appropriately inclose, adorn, and cultivate the open ground around said building, and shall hereafter keep said grounds and building in a sightly condition.

SEC. 5. [Relates exclusively to the Boston Society of Natural History.]

SEC. 6. [Relates to forfeiture of grounds and buildings in the event of non-compliance with conditions specified above.]

SEC. 7. The above-named societies shall not cover with their buildings more than one third of the area granted to them respectively.

SEC. 8. The Commissioners are hereby instructed to reserve from sale the lots fronting on said square on Boylston, Clarendon, and Newbury Streets, until said societies shall, by inclosure and improvements, put said square in a sightly and attractive condition.

SEC. 9.* Upon the passage of this act, the Governor, with the advice and consent of the Council, shall appoint three disinterested persons, who shall appraise the value of all the lands specified in the third and eighth sections of this act, and make a return of said appraisal to the Governor and Council; and if when the lands mentioned in section eight shall have been sold, the proceeds of such sales shall not be equal to the whole amount of the appraisal above mentioned, then the societies named in this act shall pay the amount of such deficit into the treasury of the Commonwealth, for the school fund, in proportion to the area granted to them respectively.

SEC. 10.* This act shall be null and void unless its provisions shall be accepted within one year, by the Massachusetts Institute of Technology and the Boston Society of Natural History, so far as they apply to those societies respectively.

*Amendments to original bill.

*DISCUSSION OF THE PRECISION OF MEASUREMENTS.**

BY SILAS W. HOLMAN, S.B.

(CONCLUDED.)

Investigation of Special Problems. As further illustrations of the application of the foregoing methods, and to illustrate the way in which any considerable investigation presents for solution its own special line of problems, the following discussions are given.

Cradle Dynamometer. The principle and operation of the Brackett Cradle Dynamometer are known to electricians. The cradle consists of a platform suspended at each end from a horizontal knife-edge, both having their edges in the same line. If the rate at which mechanical work is put into a dynamo is to be measured, the dynamo is placed upon the platform with its axis of rotation as nearly as possible in the line of the knife-edges. The centre of gravity of the whole system is brought up close to the same line by means of counterpoise weights above the edges. The rotatory moment applied to the machine is counterbalanced by a known weight, w, applied at a known distance, l, along a horizontal arm rigidly attached to the cradle; and the number, n, of rotations per minute of the dynamo shaft is counted. We have thus to measure three quantities, w, l, and n. But a study of the reliability of the cradle dynamometer involves more than the consideration of the exactness with which the quantities w, l, and n can be observed. The general action of the instrument must be considered to see whether there are in its adjustment or action, during or before a run, any causes which might tend to produce errors, whose existence might perhaps not be indicated by the action of the apparatus at the time. A discovery of such would lead to their study with a view to finding the conditions governing the design or use of the dynamometer.

It is, of course, impossible to maintain the dynamometer absolutely at its normal position at all times during measurement; *i. e.*, to keep its pointer at the zero or fiducial mark. It is therefore essential that the centre of gravity of the whole system should be sufficiently near the line of the knife-edges, so that the failure to adjust to zero during a run shall produce a sufficiently small effect; that is, it is necessary that the system, like a balance in weighing, shall have a sufficient sensitiveness. If the axis of the dynamo shaft were adjusted as nearly as possible to the line of the knife-edges, with the belt off, still on putting the belt on for a run there would be introduced by the belt-pull a moment of rotation about that line, because the adjustment could

* Copyrighted, 1888, by S. W. Holman.

not be absolute. We must therefore find whether by making the zero adjustment with the belt on, thus counterpoising this erroneous moment in large part, we may sufficiently eliminate its effect. Then there arises the very important question as to the rigidity essential in the whole system. Under the belt-pull the shaft axis and the centre of gravity of the whole system must be somewhat displaced. How small must this be in order to be of no sensible effect; that is, how rigid must the system be in order that the erroneous moment introduced either by the belt-pull acting through the displaced axis, or by the great weight of the whole system acting through its displaced centre of gravity, may be negligible or of the same effect as the other unavoidable sources of error. These and some other points will be now developed. In order, however, to make the problem cover a fairly illustrative case of use of the dynamometer, it will be stated as follows: —

Desired to 1 part in 100 the efficiency of conversion, E, of a 60 incandescent light shunt dynamo, the measurements of power to be made by the cradle dynamometer. Given in advance the rough values: — current $= c = 60.$ amp.; volts at terminals of dynamo $= v =$ 75. volts; resistance of armature $= r_a = 0.003$ ohms; resistance of field coils $r_f = 20.$ ohms; number of rotations of armature per minute $= n =$ 1400.; length of fixed arm for weights $= l = 3.4$ ft.; diameter of dynamo pulley $= 2R = 10$ inches; weight of dynamo + dynamometer $= P =$ 3,000 lbs.; efficiency of conversion $= E =$ about 90 per cent. Required the closeness necessary in the component measurements and in the adjustments, and a study of the rigidity necessary in the whole system. How far should π be carried in the computation, and how closely should the factor (746) for reduction of volts to horse-power be computed?

Let L denote the total rate of electrical output in horse-power, and W the rate of application of mechanical power. Then $E = \frac{L}{W} = 0.9$. For shunt machine,

$$L = \left(cv + c^2 r_a + \left(\frac{v}{r_f}\right)^2 r_f\right) \frac{1}{746} = 6.4 \text{ h. p. approx.}$$

In the parenthesis $c^2 r_a$ is written for $c^2{}_a r_a$, as being a sufficiently close approximation.

Whence $W = 7.1$ h.p. approx. And as $W = \frac{2\pi lnw}{33000.}$, we find $w = 8$ lbs.

It will be convenient if we can separate mechanical from electrical quantities in the discussion. This we may accomplish by assigning

proper relative precision* to the factors L and W, and treating each by itself. Since each of these contain about the same number of observed quantities as the other, it will be sufficiently close to write

$$\frac{\Delta W}{W} = \frac{\Delta L}{L} = \frac{1}{\sqrt{2}} \cdot \frac{\Delta E}{E} = \frac{0.01}{\sqrt{2}} = 0.007$$

Electrical.— By general method. *N. B.*— In differentiating with respect to c, the term $c^2 r_a$ may be dropped, since it is only $\frac{1}{4\,5\,0}$th of cv; and in differentiating with respect to v, the term $\frac{v^2}{r_f}$ may similarly be dropped. $\frac{dL}{dc} = \frac{v}{746} = 0.10$; $\frac{dL}{dr_a} = \frac{c^2}{746} = 5.$; $\frac{dL}{dv} = \frac{c}{746} = 0.09$; $\frac{dL}{dr_f} = -\frac{v^2}{746 r_f^2} = -0.02$. $\Delta L = 0.007 \times 6.4 = 0.045$; $\frac{\Delta L}{\sqrt{3}} = 0.027$, using $n = 3$ because r_a may be neglected, as inspection will show.

$\delta c = 0.027 \div 0.10 = 0.27$ amp., $\delta r_a = 0.027 \div 5 = 0.005$ ohms.

$\delta v = 0.027 \div 0.09 = 0.3$ volt, $\delta r_f = 0.027 \div 0.02 = 1.4$ ohms.

Hence r_a may be neglected altogether, and r_f must be measured with coils at temperature attained during the run.

Also, $\frac{\Delta 746}{746} < \frac{1}{10} \cdot \frac{\delta L}{L} < 0.0007$ $\therefore \Delta 746 < 0.5$.

Mechanical.—By factors. $\frac{\delta l}{l} = \frac{\delta n}{n} = \frac{\delta w}{w} = \frac{1}{\sqrt{3}} \frac{\Delta W}{W} = 0.004$

$\delta l = 0.004 \times 3.4 = 0.014$ ft. $= 0.17$ inch.

$\delta n = 0.004 \times 1400 = 5.6$ rota. p. m.

$\delta w = 0.004 \times 8 = 0.03$ lbs. $= 0.5$ oz.

$\frac{\delta \pi}{\pi} < \frac{1}{10} \cdot \frac{\delta w}{w} < 0.0004$, $\delta \pi < 0.0012$ $\therefore \pi = 3.142$ is sufficient.

Sensitiveness and Index Error. — The sensitiveness of the whole system to turn about the knife-edges is measured by the weight p (to be found by trial) necessary, when suspended at the distance l along

* Suppose $M = f(M_1, M_2, \ldots, M_r, M_s', \ldots, M_t)$ when all M's are observed quantities, and that $f(\,)$ is capable of separation into two (or more) factors each a function of observed quantities, so that

$$M = f(M_1, \ldots, M_t) = \phi(M_1, \ldots, M_r) \cdot \rho(M_s \ldots, M_t).$$

Let r and p denote the number of quantities in $\phi(\,)$ and $\rho(\,)$, respectively. Then for equal effects

$$\frac{\Delta \phi(\,)}{\phi(\,)} = \sqrt{\frac{r}{n}} \cdot \frac{\Delta M}{M} \quad \text{and} \quad \frac{\Delta \rho(\,)}{\rho(\,)} = \sqrt{\frac{p}{n}} \cdot \frac{\Delta M}{M}$$

where $\frac{\Delta \phi(\,)}{\phi(\,)}$ and $\frac{\Delta \rho(\,)}{\rho(\,)}$ are the fractional precision of $\phi(\,)$ and $\rho(\,)$, respectively.

the lever arm, to move the index from zero to one division of its scale. Suppose n = average number of divisions unavoidable error in adjusting to zero or normal position during run. Then $\frac{np}{w}$ is the fractional error in total weight w at l due to this source. To be negligible this must be less than $\frac{1}{10} \cdot \frac{\delta w}{w}$. $\therefore p < \frac{1}{10} \cdot \frac{\delta w}{w} \cdot \frac{w}{n}$. For the case in hand $w = 8$ lbs., and suppose $n = 0.25$ division (m.m.), and $\frac{\delta w}{w} = 0.004$, $\therefore p = 0.0004 \times \frac{8}{0.25} = 0.013$ lbs. $= 0.2$ oz. This limit may be easily reached. Ten times this amount would cause an error of the same magnitude as $\frac{\delta w}{w}$.

Shaft to Line of Knife-Edges, and Zero Adjustment. — How closely must this adjustment be made with the belt off? Let $2a$ = sum of tensions on two sides of belt. Assume for simplicity, at present, a parallel belt. Whether the belt is at rest or running the resultant pull is about the same in amount and direction; and as at time of weighing there is rotation without translation, there must be a resultant through axis of shaft equal to $2a$, and in same direction. If this axis is out of line of knife-edges by a perpendicular distance, d, there is on the dynamometer a moment not exerted in rotating the armature but still to be counterbalanced at l; *i. e.*, an erroneous moment, of amount $2ad \sin \theta$, where θ is the angle between direction of resultant belt-pull and direction of d, an angle equally likely to have any value. Let R = radius of pulley on dynamo, $b = T - S$ = excess of tension of tight over slack side of belt. Then bR = driving moment. Hence fractional error from imperfect adjustment, *i. e.*, ratio of erroneous to driving moment, is

$$\frac{2\,ad \sin \theta}{bR}$$

for which we must find a in terms of b. For leather belt on iron pulley $T \div S$ cannot be more than about $\frac{5}{3}$ without excessive slip; and on tight dynamo belts it is likely to be much more than this. Hence

$$\frac{T}{S} = \frac{a + \frac{b}{2}}{a - \frac{b}{2}} = \frac{5}{3} \therefore a = 2b$$

as a least value, and $a = 5b$ would be nearer an average amount. Sub-

stituting the latter *under the assumption* that it is *constant, i.e.*, that the resultant belt-pull remains constant, gives

$$\frac{2ad \sin\theta}{bR} = 10\,\frac{d}{R}\sin\theta$$

This, then, would be the fractional error if shaft were aligned with knife-edges, and dynamometer were brought to zero position with belt off, and *not* again adjusted with belt on, which would be the easiest, but, as will be seen, a very inexact procedure. In order that this error may become negligible,

$$10\,\frac{d}{R}\sin\theta < \tfrac{1}{10}\cdot\frac{\delta w}{w} \therefore d < \tfrac{1}{10}\cdot\frac{\delta w.}{w}\,\frac{R}{10\sin\theta.}$$

Of course θ is always unknown. We may therefore solve for its average value $\frac{2}{\pi}$ or $\frac{2}{3}$ approx. In the present case $R = 5$ inches, whence $d = 0.0004 \times \frac{5}{10 \times \frac{2}{3}} = 0.0003$ inch, in order to be negligible, or 0.003 inch to be of same effect as $\frac{w.}{w}$ Obviously either of these limits is utterly beyond reach, and hence the dynamometer *must* be adjusted to zero or normal position *with belt on and strained* to full tension at which it is to be run. If this were done the error would be fully compensated, *provided* that the belt-pull remained constant and the index were kept at zero at all times, and, also, that d remained constant,—a point to be considered later. But all of these provisions are impossible of fulfillment, and must, therefore, be further discussed. First, then, as index cannot be returned to zero at time of weighing within n divisions ($n = 0.25$ as already stated for this case), we must find how small d must be in order that this unavoidable error may be negligible. Moving index over n divisions will turn dynamometer through a small angle $\delta\theta$, such that $\delta\theta = \tan^{-1}\frac{n}{l}$. Now the change in erroneous fractional moment due to this will be

$$\frac{d}{d\theta}\left(10\,\frac{d}{R}\sin\theta\right) = -10\,\frac{d}{R}\cos\theta \quad \therefore \delta\left(10\,\frac{d}{R}\sin\theta\right) = -10\,\frac{d}{R}\cos\theta.\delta\theta.$$

To be negligible this must be less than $\frac{1}{10}\,\frac{\delta w}{w}$

$$\therefore d < \tfrac{1}{10}\cdot\frac{\delta w}{w}\,\frac{R}{10\cos\theta.\delta\theta}$$

For the case, in hand $n = 0.25$ mm., and $l = 3.4$ ft. $= 1040.$ mm.

$$\therefore \delta\theta = \tan\theta = \frac{n}{l} = \frac{0.25}{1040.} = 0.00\,025,$$

and to be of negligible effect for average value, $\frac{2}{\pi}$, of $\cos\theta$

$$d < 0.0004 \frac{5.}{10 \times \frac{2}{3} \times 0.00025} = 1.2 \text{ inch.}$$

Thus so far as error from erroneous moment of belt-pull owing to imperfect zero adjustment is concerned, a very rough adjustment to line of knife-edges will suffice.

But the assumption that the belt-pull is the same when the belt is running as when stationary, and that it remains constant during a run, —apart from fluctuating changes which neutralize each other,— is one which persons familiar with leather belts in practice will not readily grant. Even under favorable conditions, the quantity $2a$, when the belt is running, is liable to differ by several per cent from its value when the belt is stationary. Hence we must see how this affects the admissible value of d. Let us compute the value of d, which would lead to a negligible error for a ten per cent change in the total belt-pull. Obviously this would be ten times as great as the value found in the solution for the error due to the total belt-pull; *i. e.*, it would be

$$d' = 10 \times 0.0003 \text{ inch} = 0.003 \text{ inch},$$

or to be of same effect as $\frac{w}{w}$, $d' = 0.03$ inch. There are no sufficient data to determine whether a change of ten per cent is unusual; but in my opinion it is not so. Any permanent change in belt-pull would be indicated by changed position of rest after the run. Thus the alignment of axis to knife-edges must be made with very great care, in order that the unavoidable errors may not be greater than those coming from δw, δw, etc., and it can hardly be rendered much smaller than these.

From the considerations of this section we then infer that

Dynamo shaft must be adjusted as nearly as possible to line of knife-edges.

Dynamometer *must* be adjusted to zero with belt on and tightened.

Belt should not be unduly tight.

Radius of dynamo pulley should be as large as possible.

Yielding of Structure under Belt-Pull. Erroneous Belt-Pull. — The system or structure consisting of the dynamometer and the attached dynamo cannot be absolutely rigid. The belt-pull is large (200 to 500

lbs., say, in present case). Under this stress the structure is strained, and the shaft is thus displaced from the line of the knife-edges. Also, as the shaft is not an absolute fit in its journals, it may "climb" slightly in running, with an effect similar to the above. We have first to consider the erroneous moment due to the belt-pull, arising from this yielding. This problem is similar to the one solved in the last section. Let d be the amount of displacement of axis, measured at the pulley and normally to the line of the knife-edges. That part of d which is constant will be compensated by the adjustment to zero with the belt on. That part which is rapidly fluctuating will eliminate itself; and the component of d in the direction of the belt-pull will not be effective. Only the progressive change in d will enter into the result. To study the effect of this we have to differentiate the expression for the fractional erroneous moment with respect to d.

$$\frac{d}{dd}\left(10\frac{d}{R}\sin\Theta\right)=\frac{10}{R}\sin\Theta$$

Of course the tendency to greatest yielding will be in the direction of the belt-pull. But owing to the form of the structure, the direction of d will usually be more or less out of that line. The value of Θ would have no general average. Let us solve for $\Theta=90°$. Then for case in hand, to be negligible,

$$\delta d<\tfrac{1}{10}\cdot\frac{\delta w}{w}\cdot\frac{R}{10\sin 90°}<0.00\ 02\text{ inch},$$

or 0.002 inch to be of same effect as $\frac{\delta w}{w}$. This shows the vital importance of great rigidity, and leads us to inquire in what direction the yielding will probably be least. A consideration of the form of the system shows that this will be the vertical direction. Hence the belt should be run vertically, and, preferably, downward. Thus

Whole system must be very rigid.

Belt should run downward from dynamo pulley.

Dynamo must be adjusted to zero, with belt on and tightened.

Yielding. Displacement of Centre of Gravity. — Let h be the horizontal and v the vertical component (referred to the dynamometer in its normal position) of the displacement D of the centre of gravity of the whole system under the belt-pull (or for any cause), D being measured perpendicularly to the line of the knife-edges. Let P represent the weight of the whole apparatus. The vertical displacement produces

no effect except to slightly change the sensitiveness. The fractional error in the measured moment would be $\frac{Ph}{wl}$, which obviously diminishes as the weight of the whole is less and as the value of wl increases, *i.e.*, as the rate of output is larger. If the dynamometer is adjusted to zero with the belt on, then the constant part of this error is eliminated, and the error is reduced to $\frac{P.\delta h}{wl}$, when δh represents the permanent or progressive change in h, since fluctuating changes eliminate themselves. To be negligible,

$$\delta h < 1\tfrac{1}{0}.\ \frac{\delta w}{w}.\ \frac{wl}{P}$$

In the present case this gives

$$\delta h < 0.0004 \times \frac{8 \times 3.4}{3{,}000} = 0.000004 \text{ ft.} = 0.00005 \text{ inch,}$$

or 0.0005 inch in order to be of same effect as $\frac{\delta w}{w}$. Obviously this would require enormous rigidity of construction and attachment with a belt running in any other direction than that (downward) of greatest resistance, and very great resistance in that case. Hence,

Very great rigidity of construction and attachment in every part is essential in accurate work with a cradle dynamometer.

Belt should run vertically downward from dynamo pulley.

The greater the output and the smaller the weight of the apparatus, the better the result.

It would obviously be of decided advantage to drive the dynamo by means of a *couple without thrust* upon the axis if possible.

Position of Centre of Gravity. — To find experimentally the distance x of the centre of gravity below the knife-edges: Use letters with former significance, then p = weight at l necessary to tip system through such small angle φ that the index moves over one division of the scale. Then

$$Px \tan \varphi = pl, \tan \varphi = \frac{1}{l} \therefore x = \frac{pl^2}{P}.$$

For case in hand, suppose p to have been found by trial as 0.1 oz. = 0.06 lbs., when system was in adjustment. Then

$$x = \frac{0.06 \times 1040^2}{3000.} = 22. \text{ mm.}$$

Tangent Galvanometer. It is of importance to know the closeness necessary in the component measurements, in the corrections, in the adjustments, etc., necessary in the tangent galvanometer of the form ordinarily employed in the laboratory. The following discussion affords not only this knowledge, but a basis for computing the dimensions of such an instrument for any desired work. The galvanometer here discussed is of a type having a single coil of n turns; radius $r =$ 20. cm., about; breadth $= 2b = 2$ cm., about; depth $= 2d = 2.4$ cm. about; needle, with distance between poles, $= 2l = 1$ cm., about, suspended by single silk fibre (coeff. torsion $= \Theta$), and carrying glass index read to 0°.1 by estimation on circle of about 10 cm. diameter, parallax error being reduced by use of mirror. The expression for the current is, in its simple form,

$$C = \frac{10Hr}{2\pi n} \cdot \tan \varphi.$$

But the second member requires several corrections and assumes several adjustments to be properly made. The corrections may be introduced in the form of factors, so that the whole may most readily be treated by the method of factors. These factors will be indicated as we go on, and will be denoted by m_1, m_2, etc. The solution will be made to find the closeness necessary in the components, adjustments, etc., to produce *separately* $\frac{\delta C}{C} = 0.001$. The attainable closeness will also be considered.

$m_1 = \frac{10}{2\pi}$ is a numerical factor which should, of course, be taken to $\frac{\delta m_1}{m_1} < \frac{1}{10} \times 0.001$ whence π should be taken to 3.1416.

$m_2 = H = 0.17$ abt. $\therefore \frac{\delta H}{H} = 0.001$ $\therefore \delta H = 0.00\,02$ abt.

The measurement of H with this precision is difficult; and diurnal and local variations are of about this order of magnitude, though the latter may be much larger. The nature and magnitude of the errors entering into the measurement of H depend so entirely upon the method and instrument employed that they will not be here discussed. It will be assumed that H can be found to less than $\frac{\delta H}{H} = 0.003$. It should be remembered that *relative* measurements of C are independent of the absolute value of H, and are subject only to the variations in H during the measurements.

$m_3 = r$, $\delta r = 0.001 r = 0.02$ cm. Direct measurement of the diameter $2r$ by a steel scale, correct within 0.1 mm., may be made at many diameters. This is liable to errors from irregular thickness of insulation (causing uncertainty as to position of wire), from irregular winding, and from ellipticity of coils. An AD for r as small as 0.02 cm. may be obtained on a good coil by careful work. It is usually better to measure the outer circumference of the coil by a steel tape, and the average thickness of the coil, and thence to compute r; or, better still, to measure the circumference of each layer as it is wound. A circumference measurement to $AD = 0.01$ cm. would give $\delta r = \frac{0.01}{6.3}$ cm., since circumference $= 2\pi r$. Sometimes the length of the wire to compose the coil is measured before winding, and r computed from this length and n. But liability to stretch renders this result unreliable except with heavy wire wound and measured with great care.

$m_4 = n$. This is necessarily a whole number, and unless $n = 1000$ or more, cannot be in error by one turn without producing a greater effect than $\frac{\delta C}{C} = 0.001$.

$m_5 = \tan \varphi \therefore \delta m_5 = \delta \tan \varphi = 0.001 \tan \varphi$. Since $\tan \varphi$ is a variable, we must study its δ as a fraction of φ.

$\frac{d(\tan \varphi)}{d\varphi} = \sec^2 \varphi \therefore \frac{\delta \tan \varphi}{\tan \varphi} = \frac{2\,\delta\varphi}{\sin 2\varphi}$. Several important points deducible from this expression will be given later. $\frac{\delta \tan \varphi}{\tan \varphi}$ is a minimum for $\varphi = 45°$, as will be seen by inspection. This value only will be considered here. For this, $\frac{\delta \tan \varphi}{\tan \varphi} = \frac{\delta C}{C} = 0.001$, $\delta\varphi = 0.001, \frac{\sin 2\times 45°}{2}$ $= 0.0005$. The arc whose length is radius is $57°.3$ appr. $\therefore \delta\varphi° = 0.0005 \times 57. = 0°.03$ about. The galvanometer considered is read to $0°.1$ by eye estimation of tenths of degree. It is assumed that in a single estimation the maximum error will be $\frac{1}{20}$ degree. A value of φ is the mean of four readings. The case falls under the first special law of deviations. Therefore the ad of single estimation $= \frac{0.05}{2} = 0.025$, and for the mean of the four readings, $\delta' = \frac{0.025}{\sqrt{4}} = 0°.013$. Thus the errors of estimation in reading $\varphi =$ less than $\frac{1}{2}$ the δ prescribed. But there are also errors in φ from eccentricity (eliminated by averaging), irregular graduation, inclination of mirror and graduated circle to horizontal, inclina-

tion of plane of coils from vertical, and displacement of plane of coils from magnetic meridian. Irregularity of graduation must be separately studied and corrected, though the averaging of four readings reduces its effect. The other sources of error mentioned will be discussed later, and it will be shown that with care they can be rendered negligible in effect. The combined errors of estimation and graduation may easily fall within $\delta\varphi = 0°.03$.

In discussing the correction terms we may desire to know: 1st, Values of δ's to make the correction term either of a given effect, $\frac{\delta C}{C}$, or negligible so that it may be omitted. 2d, Values of the magnitude of the quantities entering into the correction which will make its effect either of a given amount, or zero, or negligible.

The correction terms are all factors of the form $m = (1 + A)$ when A is a function of one or more quantities, x, y, etc., and is small, relatively, to unity. Hence,

$$\frac{dm}{dx} = \frac{d(1+A)}{dx} = \frac{dA}{dx} \quad \therefore \quad \delta m = \delta A,$$

and as $m = 1$ (sensibly).

$$\frac{\delta m}{m} = \frac{\delta A}{1} = \delta A.$$

Thus, for $\frac{\delta m}{m} = 0.001$, $\delta A = 0.001$, and for $\frac{\delta m}{m} < 0.0001$; *i. e.*, negligible, $\delta A < 0.0001$.

$m_6 = \left(1 + \frac{1}{2}\cdot\frac{b^2}{r^2} - \frac{1}{3}\cdot\frac{d^2}{r^2}\right)$ is the correction factor for dimensions of coil-section, when $2b$ and $2d$ do not exceed 0.1, or, better, 0.05 of r. Consider first values of δ's which, with the given magnitudes of $2b$ and $2d$, will make $\frac{\delta m_6}{m_6}$ negligible; *i. e.*, less than $\frac{1}{10}\times 0.001$. We must then have $\delta A = \delta\left(\frac{1}{2}\cdot\frac{b^2}{r^2} - \frac{1}{3}\cdot\frac{d^2}{r^2}\right) < 0.0001$. As r must be determined more closely for use in m_3 than for this correction, δr may be here disregarded. Applying XXII. for equal effects of δ's, we have

$$\Delta = 0.0001,\ n = 2,\ \therefore \frac{\Delta}{\sqrt{n}} = 0.00007.$$

$\frac{dA}{db} = \frac{b}{r^2}\cdot\frac{dA}{dd} = -\frac{2}{3}\cdot\frac{d}{r^2}$, or as $2b$ and $2d$ are the measured quantities,

$\frac{dA}{d2b} = \frac{b}{2r^2}\cdot\frac{dA}{d2d} = -\frac{1}{3}\cdot\frac{d}{r^2}$, $\therefore \delta 2b = \frac{\Delta}{\sqrt{n}}\Big/\frac{dA}{d2b} = 0.06$ cm., $\delta 2d = 0.07$ cm.

Of course we might similarly compute the values of $\delta 2b$ and $\delta 2d$ for $\frac{\delta C}{C} = 0.001$, but this is unnecessary, as it is obvious that the narrower limit just computed can be attained, and thus the correction rendered sensibly exact.

For magnitudes of b and d. The correction will be negligible when $A < 0.0001$. Inspection shows that A is zero when $\frac{1}{2} \cdot \frac{b^2}{r^2} = \frac{1}{3} \cdot \frac{d^2}{r^2}$; *i. e.*, $\frac{b^2}{d^2} = \frac{2}{3}$, or $\frac{b}{d} = \frac{5}{6}$ approx. For the given galvanometer it is only necessary then to have these proportions exact within $\delta 2b = 0.06$ cm., and $\delta 2d = 0.07$ cm., in order to have the correction vanish. It is obvious that this proportion of $b : d$ may be considerably departed from without loss of accuracy, if only the correction be carefully determined and applied. It should, however, be borne in mind that the form of the correction assumes a uniform distribution of wires in the coil-section.

$m_7 = \left(1 - \frac{3}{4} \cdot \frac{l^2}{r^2} + \frac{15}{4} \cdot \frac{l^2}{r^2} \sin^2\varphi\right)$ is the correction factor for length of needle when $2l$ does not exceed 0.1 to 0.05 of r. As in m_6 we may consider r as exact. A similar statement applies to φ. We have, therefore, to deal only with $\delta 2l$. Consider first values of $\delta 2l$, which, with the given magnitude of $2l$, will render $\frac{\delta m_7}{m_7}$ negligible; *i. e.*, < 0.0001. As A contains φ, which, though exact, is not constant, it should be studied for all values of φ. But for its best work the galvanometer will be used only between $\varphi = 30°$ and $60°$, and it will be shown that A increases from $\varphi = 26°.6$ upward. Hence it will suffice to compute for the worst case. Substituting, then, $\varphi = 60°$, we find $A = 2\frac{l^2}{r^2}$ nearly.

$$\therefore \frac{dA}{dl} = \frac{4l}{r^2}, \quad \therefore \quad \delta l = \frac{r^2}{4l} \cdot \delta A, \quad \therefore \quad \delta 2l = \frac{r^2}{2l} \cdot \delta A = 0.04 \text{ cm.},$$

which is easily attainable. Note that $2l$ is the distance between the magnetic poles of the needle, which is about 0.85 of the whole length if the needle is a straight, thin prism.

The correction will vanish when $\frac{3}{4} \cdot \frac{l^2}{r^2} = \frac{15}{4} \cdot \frac{l^2}{r^2} \sin^2\varphi$. Solving this for φ gives $\varphi = 26°.6$. Hence the correction vanishes, whatever the length $2l$ (within limit $0.1r$), when the deflection is $26°.6$. For the given galvanometer the correction cannot be disregarded nor rendered negligible between 30° and 60°, because 1 cm. is about as small as $2l$ can be made

without introducing too great torsion correction, and $\delta 2l$ cannot be reduced much below 0.04 cm.

$m_8 = \left(1 + \frac{\varphi\,\Theta}{\sin\varphi}\right)$ is the correction factor for torsion when this is not unduly great. This does not take account of initial torsion, which is in part eliminated by reading reverse deflections. In this factor φ may be regarded as exact, for reasons similar to those given for r and φ in m_7 and m_6. But though exact, φ varies. Inspection shows that as φ increases more rapidly than its sine, the value of m_8 increases up to $\varphi = 90°$. Hence, for reasons similar to those given under m_7 in a similar case, we may consider only $\varphi = 60°$. Substituting this value gives $A = 70.\Theta$ nearly. To find value of $\delta\Theta$ to make $\frac{\delta m_8}{m_8}$ negligible, *i.e.*, $\delta A < 0.0001$, we have

$$\frac{dA}{d\Theta} = 70, \quad \therefore \ \delta\Theta = \frac{0.0001}{70} = 0.00000014.$$

To ascertain whether this is attainable in the given instrument, we must know how closely Θ may be found in it. With the needle strongly magnetized and suspended by a single fine fibre, Θ may be as small as 0.00005, or even 0.00001, and may be determined within ten per cent of its value; *i. e.*, with $\delta\Theta = 0.000005$ to 0.000001. Hence, torsion factor in such case may be determined with such closeness that $\frac{\delta m_8}{m_8}$ is negligible, but the correction must be applied in this grade of work.

$m_9 = \left(1 + \frac{3}{2}\,\frac{x^2 + y^2 - 2z^2}{r^2}\right)$ is the correction factor which serves to correct for the displacement of the centre of the needle from the centre of the galvanometer coil, x and y being the rectangular components of this displacement in the plane of the coils, and z the component perpendicular to that plane, x, y, and z being small in proportion to r. By inspection, therefore, it appears that along any surface whose equation is $x^2 + y^2 - 2z^2 = 0$ the correction would disappear. If a limiting value a be assigned to x, y, and z, each, the correction will be a maximum when $z = 0$ and $x = y = a$, or when $x = y = 0$, and $z = a$. As all values between 0 and a will occur, the correction term may have any value from 1 to $1 \pm 3\frac{a^2}{r^2}$. The law of distribution of the errors will be a special one, but will not differ widely from the general one. Hence the ad may be assumed as about $\frac{3}{4}\cdot\frac{a^2}{r^2}$. [See paragraph on Estimated

Precision Measures, p. 198.] In order, then, that m_9 be negligible, we may write

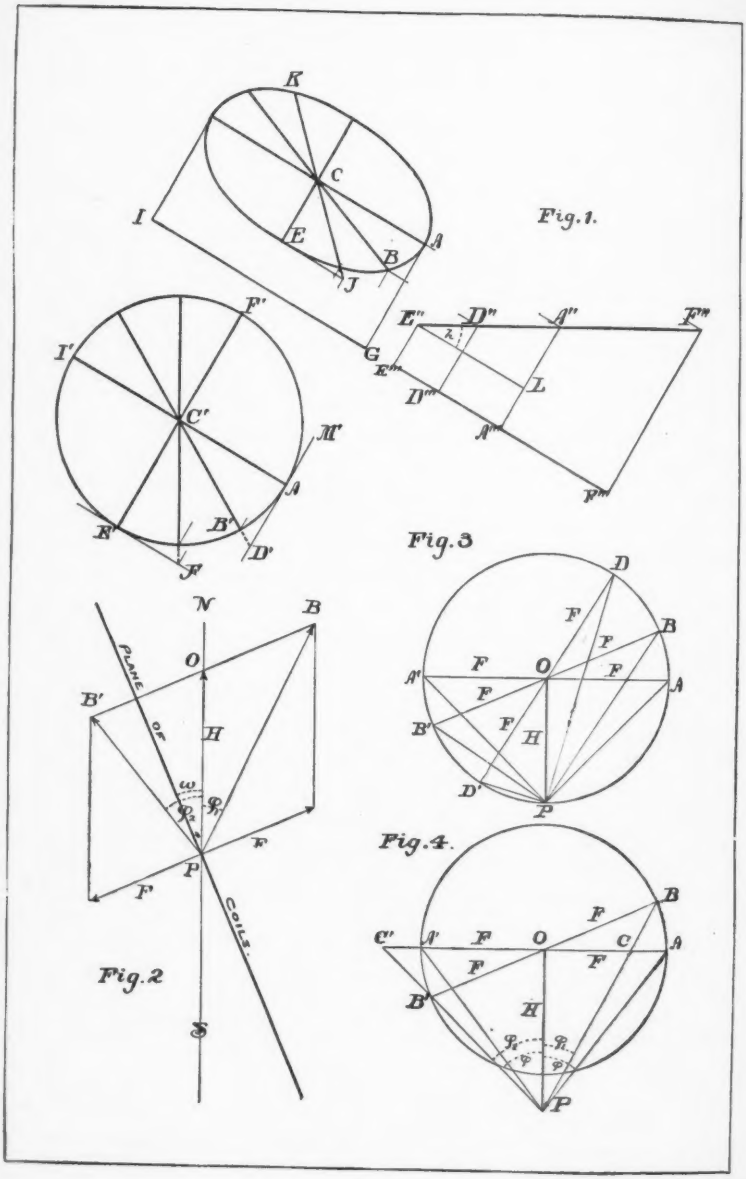
$$\tfrac{3}{4}\cdot\frac{a^2}{r^2}<\tfrac{1}{10}\times 0.001=0.0001 \quad \therefore a^2<0.0001\frac{4\times 400}{3}=0.05 \text{ cm.} \quad \therefore a<0.22 \text{ cm.}$$

That is, the centre of the needle should be within a radius (on the average) of less than about $\frac{1}{4}$ cm., which is easily possible.

m_{10} is the correction factor for the inclination of the circle to the horizontal, which would, of course, introduce error into φ. The graduated circle is assumed to be rigidly attached to the mirror. Suppose the circle and mirror inclined by an angle h to the horizontal. The line of sight is always normal to the mirror. Imagine a right circular cylinder erected with the graduated circle as a base. Then the accompanying figures will represent projections of this cylinder. $E'''F'''$ will be the projection of the circle upon a vertical plane. GI will be another projection of the circle upon a plane at right angles to the former and parallel to the axis of the cylinder, — which, of course, is the direction of sight in reading. $E'A'F'I'$ is the projection of the circle on a plane parallel to itself, and, therefore, shows the circle in its true dimensions, as it is always seen, because the lines of projection are here the lines of sight. The *horizontal* plane swept through by the index would be then that indicated by $ABEK—A''D''E''$, making an angle h with the plane of the circle. This plane will intersect the cylinder in an ellipse $ABEK—A''D''E''—A'B'E'I'F'$.

1°. Let A, A', A'' be the zero point of the circle and index. Let the needle be deflected to the position D'', B, B'. The real angle of deflection φ of the needle in the horizontal plane will be represented in the diagram only by its projections $ACB—A'C'B'$. The observed angle is $\varphi'=A'C'B'$, which is, of course, the projection of φ upon the base of the cylinder. We must find some equation connecting φ and φ'. Pass a plane tangent to the cylinder along the element $AG—A'$. Its trace in the plane of the circle will be $M'A'D'$. Prolong $C'B'$ until it intersects $M'A'$ at D', and locate on the other projections the corresponding points D'', D'''. Then $\tan\varphi'=\dfrac{A''D''}{r}$ when $r=AC=A'C'=E'C'=$ radius of circle. Also, $\tan\varphi=\dfrac{A'D'}{r}=\dfrac{A'''D'''}{r}$. Hence $\dfrac{\tan\varphi'}{\tan\varphi}=\dfrac{A'''D'''}{A''D''}=\cos h$

$\therefore \tan\varphi=\dfrac{\tan\varphi'}{\cos h}$, and we may write $C=\dfrac{10H}{G}\dfrac{\tan\varphi'}{\cos h}$. The effect of inclining the mirror *in this case* is thus the same as inclining the coils in the cosine galvanometer.


K
C
I
E
A
B
J
G
Fig. 1.
E''
D''
A''
F''
k
E'''
L
D'''
A'''
F'''
F'
I'
C'
M'
A
E'
B'
D'
F
Fig. 3
D
F
B
F
F
A'
O
F
A
F
B'
F
H
D'
P
N
B
PLANE OF
O
B'
H
ω
φ
φ
F
P
F
COILS.
S
Fig. 2
Fig. 4.
B
F
C'
A'
F
O
C
A
F
F
B'
H
φ
φ
P

2°. If the angles be measured from E, E', E'' as zero position, then $\tan\varphi = \tan \mathcal{F}CE$ revolved $= \frac{\mathcal{F}E}{A''E''}$; $\tan\varphi' = \tan \mathcal{F}C'E' = \frac{\mathcal{F}E'}{r} = \frac{\mathcal{F}E}{r}$ $\therefore$ $\frac{\tan\varphi'}{\tan\varphi} = \frac{A''E''}{r} = \frac{A''E''}{E''L} = \frac{1}{\cos h}$ $\therefore$ $\tan\varphi = \tan\varphi' \cos h$.

3°. If the zero line be neither AC nor EC then the correction will be unsymmetrical, but, as it will not in any case differ widely from the above values, it is unnecessary to discuss the general expression.

It may be seen by inspection that the reading of both ends, and of reversed currents, will not affect this error. In the demonstration it has also been assumed that the projections of the centre of the needle was upon the centre of the circle. If this is not the case a variable eccentricity will be introduced, which will be eliminated by the ordinary method of reading both ends of the needle.

In order that the error from h may be negligible, we must have $\frac{\tan\varphi - \tan\varphi'}{\tan\varphi} = < 0.0001$. From equation in 1° case $\frac{\tan\varphi - \tan\varphi'}{\tan\varphi} = \frac{1 - \cos h}{1}$, and in 2° case $= \frac{\cos h - 1}{\cos h}$, which, for small values of h, $= \frac{\cos h - 1}{1}$ appr. Thus for small values of h the difference in the two cases is merely one of sign. To be negligible we have, then, $\cos h = 1 - 0.0001 = 0.9999$; whence $h < 0°.8$, which would require care in original adjustment of plane of mirror to horizontal, and corresponding care in subsequent leveling of galvanometer.

m_{11} is the correction term for ellipticity, or irregularity of coils. The strength of field at the needle due to unit current in the coils might be found by integration. This will increase in intensity as the coil becomes more elliptical. But the value of the integral will change slowly with small eccentricity of the ellipse; and as it is easy to keep the difference between the major and minor axes within limits of a fraction of a millimetre, it seems that the error may be considered as then negligible — though always tending to produce a + error in C as computed on the supposition of a circular coil. Irregular winding of the coils tends to produce a similar effect.

m_{12} is the correction factor for plane of coils not being vertical. Let v be the angle by which the plane is inclined to the vertical. The effective part of the field G is then its horizontal component only, viz.,

$G \cos v$. This error will, therefore, be negligible, similarly to m_{10}, when $1-\cos v < 0.0001$, or $v < 0°.8$ about.

m_{13} is the correction factor for plane of coils being out of magnetic meridian. If it is so, the field F at the centre, due to the current, is oblique to H and $\varphi_1 >$ or $< \varphi_2$, *i. e.*, the deflections on opposite sides of the zero are unequal. In Fig. 1 the plane of the coils is inclined by w to the west of north, *i. e.*, by a — angle. The deflection usually employed is $\frac{1}{2}(\varphi_1+\varphi_2)$, these being *the angles swept through by the pointer* in passing from its normal position when the *needle* is in the meridian to that when the needle is successively in the directions of the resultant fields with reversed currents. Of course corrections may be made for error of index from zero of scale when at normal position, but no advantage is thus gained. The error m_{13} may be eliminated by turning the coils by trial until, when corrected for initial position of pointer, $\varphi_1=\varphi_2$; but exact adjustment is troublesome, and it is, therefore, necessary to know the best process, and how small it is necessary to make w in order that it may be negligible.

In the figures F is the field due to the current in the coils; $w=$ angle between plane of coils and meridian; $\varphi =$ the true angle of deflection; φ_1 and $\varphi_2 =$ the observed deflections with reversed currents. Figures 2 and 4 show the constructions to find, by triangle of forces, the direction and magnitude of the resultant fields PA, PA', PB, PB', etc., and thus the values of φ, φ_1, and φ_2. Figure 3 is the solution for the case when $F = H$, *i. e.*, where $\varphi = 45°$, where it appears that whatever the value of w [$= AOB$, or AOD, etc.] the value of $\varphi_1+\varphi_2$ [$= BPB'$ or DPD', etc.] is always 90°, so that $\frac{1}{2}(\varphi_1+\varphi_2)$ will be φ, the true deflection. This surprising result points very strongly to the use of deflections of about 45° when *accurate* values of C are sought. Figure 4 represents the general case, and from it the following demonstration gives the general expression connecting φ, $(\varphi_1+\varphi_2)$, and w.

In OBP, $$\frac{OC}{OB}=\frac{\sin OBC}{\sin OCB}=\frac{\sin(90°+w+\varphi_1)}{\sin(90°+\varphi_1)}=\frac{\cos(w+\varphi_1)}{\cos\varphi_1}=\frac{OC}{F}$$

$$\therefore \tan\varphi_1=\frac{OC}{H}=\frac{F}{H}\cdot\frac{\cos(w+\varphi_1)}{\cos\varphi_1}=\tan\varphi\cdot\frac{\cos(w+\varphi_1)}{\cos\varphi_1}$$

$$=\tan\varphi\,[\cos w-\sin w\,.\tan\varphi_1]=\tan\varphi\cos w-\tan\varphi.\sin w\,.\tan\varphi_1$$

$$\tan\varphi_1=\frac{\tan\varphi\,.\cos w}{1+\tan\varphi\,.\sin w}.$$

In $OB'P$, $\dfrac{OC}{OB} = \dfrac{\sin OB'C}{\sin OB'B'} = \dfrac{\sin(90^\circ - w + \varphi_2)}{\sin(90^\circ - \varphi_2)} = \dfrac{\cos(\varphi_2 - w)}{\cos \varphi_2} = \dfrac{OC}{F}$.

$$\therefore \tan \varphi_2 = \frac{OC}{H} = \frac{F}{H} \cdot \frac{\cos(\varphi_2 - w)}{\cos \varphi_2} = \tan \varphi \cdot \frac{\cos(\varphi_2 - w)}{\cos \varphi_2}$$

$$= \tan \varphi \,[\cos w + \sin w \,.\, \tan \varphi_2] = \tan \varphi \cos w + \tan \varphi \,.\, \sin w \,.\, \tan \varphi_2.$$

$$\tan \varphi_2 = \frac{\tan \varphi \cos w}{1 - \tan \varphi . \sin w}$$

$$\tan(\varphi_1 + \varphi_2) = \frac{\tan \varphi_1 + \tan \varphi_2}{1 - \tan \varphi_1 . \tan \varphi_2} = \frac{\dfrac{\tan \varphi \,.\, \cos w}{1 + \tan \varphi \,.\, \sin w} + \dfrac{\tan \varphi \cos w}{1 - \tan \varphi \sin w}}{1 - \dfrac{\tan^2 \varphi \sin^2 w}{1 - \tan^2 \varphi \sin^2 w}}$$

$$= \frac{2 \tan \varphi \cos w}{1 - \tan^2 \varphi} = \frac{2 \tan \frac{1}{2}(\varphi_1 + \varphi_2)}{1 - \tan^2 \frac{1}{2}(\varphi_1 + \varphi_2)};$$

$$\therefore (1 - \tan^2 \tfrac{1}{2}(\varphi_1 + \varphi_2)) \tan \varphi \,.\, \cos w = (1 - \tan^2 \varphi) \tan \tfrac{1}{2}(\varphi_1 + \varphi_2);$$

$$\therefore \tan \varphi \,.\, \cos w \,.\, \tan^2 \tfrac{1}{2}(\varphi_1 + \varphi_2) + (1 - \tan^2 \varphi) \tan \tfrac{1}{2}(\varphi_1 + \varphi_2) = \tan \varphi \cos w;$$

$$\therefore \tan \tfrac{1}{2}(\varphi_1 + \varphi_2) = \frac{\tan^2 \varphi - 1 \pm \sqrt{\{\tan^4 \varphi - 2 \tan^2 \varphi + 1 + 4 \tan^2 \varphi \cos.^2 w\}}}{2 \tan \varphi \,.\, \cos w.}$$

The upper sign of the $\pm$ must be taken for the radical. For suppose $w = 0$, then $\sqrt{\{\text{etc.}\}} = \tan^2 \varphi + 1$ and $\tan \frac{1}{2}(\varphi_1 + \varphi_2) = \dfrac{\tan^2 \varphi - 1 \pm (\tan^2 \varphi + 1)}{2 \tan \varphi}$,

which with the upper sign is $\tan \frac{1}{2}(\varphi_1 + \varphi_2) = \dfrac{2 \tan^2 \varphi}{\tan \varphi} = \tan \varphi$, which is, of course, the proper value, while that obtained by taking the lower sign would not be so. Hence

$$\tan \tfrac{1}{2}(\varphi_1 + \varphi_2) = \frac{\tan^2 \varphi - 1 + \sqrt{\{\tan^4 \varphi + 2 \tan^2 \varphi \,.\, \cos 2w + 1\}}}{2 \tan \varphi \,.\, \cos w.}$$

For the case, already solved geometrically, when $\varphi = 45^\circ$.

$$\tan \tfrac{1}{2}(\varphi_1 + \varphi_2) = \frac{1 - 1 + \sqrt{(1 - 2 + 1 + 4 \cos^2 w)}}{2 \cos w} = \frac{2 \cos w}{2 \cos w} = 1.$$

For $\varphi = 90^\circ$ (impossible on tangent galvanometer) $\tan \frac{1}{2}(\varphi_1 + \varphi_2) = \frac{\infty}{\infty}$ which is indeterminate in form.

The simplest way to study the effect of this error is to plot a series of values of $\dfrac{\delta C}{C}$, for various values of φ, obtained by computing $\tan \frac{1}{2}(\varphi_1 +$

φ_2) by the above equation for a series of small values of w. From such a plot made with values of $\frac{\delta C}{C}$ as ordinates, and of w as abscissas, we may find that the value allowable, in order that $\frac{\delta C}{C}$, shall not exceed the negligible amount 0.0001 is about $w = 0°.5$, when the values of φ are between 30° and 60°. This closeness cannot be attained without careful adjustment of the plane of the coils by some such method as that to be described. For a limit $\frac{\delta C}{C} = 0.001$ the value of $w = 2°.5$, about, is sufficiently close, — a closeness easily reached without special attention in a well-made instrument.

Method of Adjusting Tangent Galvanometer to Meridian.— Set the graduated circle with line of zero points as nearly as practicable in plane of coils. See that index is very nearly parallel to axis of needle. Turn plane of coil until index is parallel to line of zeros. Then coil is approximately in meridian. Pass constant current to produce about $45° = \varphi_1$ (defl. of N. end to E), read both ends and take mean $= \varphi_1$. Reverse current, and find φ_2. Then $w = \varphi_2 - \varphi_1$. If w is +, the plane of coils is to W. of N.; w is always toward largest deflection. Turn plane in proper direction by w. This will be nearly right, but should be repeated, correcting now for initial position of needle, which is, of course, no longer zero. The proof is as follows: —

From page 315, $\tan \varphi_1 - \tan \varphi_2 = \tan\varphi$. $\cos w \left(\frac{1}{1 + \tan \varphi \sin w} - \frac{1}{1 - \tan \varphi \sin w}\right)$; and as $\sin w$ is quite small, $\tan \varphi . \sin w$ is negligible in denominators, and $\tan \varphi_1 - \tan \varphi_2 = \tan \varphi . \cos w\ (-2 \tan \varphi . \sin w)$ approx. $= -2 \tan^2 \varphi . \sin w \cos w = -\tan^2 \varphi . \sin 2w \therefore \sin 2w = \frac{\tan \varphi_2 - \tan \varphi_1}{\tan^2 \varphi}$

Write $\varphi_2 - \varphi_1 = \Delta$, a *small* angle, and substitute $\varphi_1 = 45° = \varphi$ approx. Then $\sin 2w = \frac{\tan (\varphi_1 + \Delta) - 1}{1}$. Now $\tan (\varphi_1 + \Delta) = \frac{\tan \varphi_1 + \tan \Delta}{1 - \tan \varphi_1 \tan \Delta}$

$= \frac{1 + \tan \Delta}{1 - \tan \Delta} = 1 + 2 \tan \Delta$ approx. $\therefore \sin 2w = 1 + 2 \tan \Delta - 1 =$ $2 \tan \Delta$, and as w and Δ are both small, $w = \Delta = \varphi_2 - \varphi_1$. For angles other than 45° the general expression for $\sin 2w = \frac{\tan \varphi_2 - \tan \varphi_1}{\tan^2 \varphi}$ must be employed.

RESULTS.

Tangent Galvanometer used between 30° *and* 60°.

	Factor.	Val. of δ for $\frac{\delta C}{C} = \frac{\delta m}{m} = 0.001$	Values attainable by correction and adjustment. δ	$\frac{\delta C}{C}$
m_1	$\frac{10}{2\pi}$	0.00 16	$[\pi = 3.1416]$	negligible.
m_2	H	0.00 017	0.00 030	0.0018
m_3	r	0.02 cm.	0.02 cm.	0.001
m_4	n	. . . .	0	0
m_5	tan ϕ	$\delta\phi = 0°.03$	$\delta\phi = 0°.03$	0.001
m_6	Dimensions of coil sec.	. . . .	$\delta 2b = \delta 2d = 0.06$ cm.	0.0001 negl.
m_7	Length of needle.	$2l = 0.9$ cm.	$\delta l = 0.04$ cm.	0.0001 negl.
m_8	Torsion.	$\theta = 0.00\,001\,4$	$\delta\theta = 0.00\,000\,14$	0.0001 negl.
m_9	Needle out of centre.	$a = 0.7$ cm.	$a = 0.22$ cm.	0.0001 negl.
m_{10}	Incl. of circle from hori.	$h = 2°.6$	$h = 0\ .8$	0.0001 negl.
m_{11}	Ellipticity of coil.	. . . .	. . . . .	— negl.
m_{12}	Coils out of vertical.	$v = 2°.6$	$v = 0°.8$	0.0001 negl.
m_{13}	Coils out of meridian	$w = 2°.5$	$w = 0°.5$	0.0001 negl.

Inspection shows that the chief source of error is in H. If each m be allowed to affect C by $\frac{\delta C}{C} = 0.001$, the resulting effect will be $\frac{\Delta C}{C} = 0.001\sqrt{13} = 0.0036$, or about 0.4 per cent. If the corrections and adjustments be made as indicated in columns 4 and 5, we shall have $\left(\frac{\Delta C}{C}\right)^2 = 0.0018^2 + 0.001^2 + 0.001^2 + 7 \times 0.0001^2(\text{negl.}) = 0.0023^2$, or $\frac{\Delta C}{C}$ = about 0.25 per cent. Relative current measurements do not involve H, and $\therefore$ for them $\Delta = 0.0014$, or about 0.15 per cent.

Tangent Galvanometer. *Best Range of Deflections.* — To determine what this range is, we have to consider the effect on $\frac{\Delta C}{C}$ of 1°, a change $\delta\varphi$ in the reading; 2°, the length of the needle; 3°, the torsion of the suspension; 4°, deviation of plane of coils from the mag-

netic meridian in the original adjustment. It will be shown that if 2° and 3° be corrected, the best working deflection, *i. e.*, the value of φ, which will make $\frac{\Delta C}{C}$ a minimum, is $\varphi = 45°$, but that any deflection from 30° to 60° is not sensibly worse than 45°, and that the range of 20° to 70° is almost as good; giving a range of currents of 3 : 1 in the first case, and 7.5 : 1 in the second. The kind of tangent galvanometer referred to is, of course, the same as elsewhere considered in these notes.

1°. *Change of $\delta\varphi$ in the Deflection Reading.* — $C = R \tan \varphi$ ∴ $\frac{\delta C}{C} = \frac{2\delta\varphi}{\sin 2\varphi}$ (p. 307). On any given instrument where φ is read by a circle, an average value of $\delta\varphi$ will be found, which is independent of φ; ∴ $\delta\varphi$ = constant. Hence $\frac{\delta C}{C}$ will be a minimum when $\sin 2\varphi$ is a maximum, *i. e.*, when $\varphi = 45°$. Moreover the value of $\frac{\delta C}{C}$ will be symmetrical about the point $\varphi = 45°$, because the value of $\sin 2\varphi$ will be so.

$\phi =$	$\frac{\delta C}{C} = \frac{2\delta\phi}{\sin 2\phi} =$
0° or 90°	± ∝
5 or 85	±0.00589
10 or 80	.00292
15 or 75	.00200
20 or 70	.00156
25 or 65	.00131
30 or 60	.00116
35 or 55	.00107
40 or 50	.00102
45 or 45	.00100

The preceding table gives values of $\frac{\delta C}{C} = \frac{2\,\delta\varphi}{\sin 2\varphi}$ for $\delta\varphi = \pm 0°.03$, which would give $\frac{\delta C}{C} = 0.001$ at $\varphi = 45°$. The table might equally well

be computed from a table of tangents, since $\frac{\delta C}{C} = \frac{\delta \tan \varphi}{\tan \varphi}$, $\delta \tan \varphi$ being the change for $\delta\varphi = \pm 0°.03$. A curve plotted with values of φ as abscissas and of $\frac{\delta C}{C}$ as ordinates, or inspection of the table, will show that up to $\varphi = 30°$ or 60° the value of $\frac{\delta C}{C}$ changes by but $\frac{1}{5}$th its value at 45°, and is therefore sensibly uniform, and even up to $\varphi = 20°$ or 70° it increases by but $\frac{1}{2}$ its value at 45°. Hence as far as $\delta\varphi$ in reading is concerned, the tangent galvanometer of this form is equally precise from 30° to 60°, and almost as much so from 20° to 70°.

2°. *Length of Needle.* — The correction for this has been already shown to be zero at $\varphi = 26°.6$. If the correction is made properly or is small enough to be negligible, the resident error will be a minimum at 26°.6, so that as far as this affects the result (*i. e.*, very slightly), the *best* working angle would be slightly under 45°.

3°. *The torsion correction* increases with φ, and hence whether it is corrected or not this would indicate an advantage in small rather than large deflections.

4°. *The deviation of the coils* from the meridian has been shown to be of no effect at $\varphi = 45°$; and as it is difficult, mainly on account of initial torsion, to obtain certainty in this adjustment, there appears here a decided reason for considering $\varphi = 45°$ the best working angle.

On the whole, then, 45° seems the best angle; but when torsion and length of needle are corrected, the range of 30° to 60° is about as good, and even 20° to 70° not decidedly worse; but beyond 20° and 70° the galvanometer should not be employed except in coarse work.

Electro-Static Capacity. *Thomson's and Gott's Methods.* — [Method described in Kempe's H'b'k of El. Test'g, Ed. 1887, pp. 335, 339.] Formula is $F_x = \frac{R}{R_x} \cdot F$. The battery power used is assumed to be sufficient to enable a change of the smallest coil in the resistance box to be perceived, so that the precision condition is $\delta R = \delta R_x$. The charges in the condensers, and therefore the sensitiveness of the apparatus, are greatest when the total resistance $R + R_x$ is as large as possible, viz., the total in the box. Hence the magnitude condition is $R + R_x = r$, a constant, or $R_x = r - R$.

By Formula XVI. for factors

$$\left(\frac{\Delta F_x}{F_x}\right)^2 = \left(\frac{\delta R}{R}\right)^2 + \left(\frac{\delta R_x}{R_x}\right)^2 = \left(\frac{1}{R^2} + \frac{1}{R_x{}^2}\right)\delta^2 R.$$

Now $\frac{\Delta F_x}{F_x}$ must be a minimum, which will occur when $\frac{1}{R^2}+\frac{1}{R^2_x}$ is so. By XXX.

$$-\frac{2}{R^3}-\frac{2}{R^3_x}\cdot\frac{d}{dR}(r-R)=0 \therefore \frac{2}{R^3}=\frac{2}{R^3_x}$$

and $R : R_x = 1$ will be the best ratio. But this will hold when $F = F_x$. The best magnitude of F is then F_x; *i.e.*, the known condenser should be equal to the unknown, or that condition should be approached as nearly as may be.

This problem is also capable of a simple solution which may serve to indicate methods for other similar ones. Substituting $R_x = r - R$ gives

$$F_x=\frac{R}{R_x}\cdot F=\frac{R}{r-R}\cdot F.$$

By definition $\frac{\delta F_x}{\delta R}=\frac{dF_x}{dR} \therefore \delta F_x=\frac{dF_x}{dR}\cdot\delta R.$

$$\therefore \delta F_x=\frac{rF}{(r-R)^2}\cdot\delta R \therefore \frac{\delta F_x}{F_x}=\frac{rF}{(r-R)^2}\cdot\frac{r-R}{RF}\cdot\delta R=\frac{r}{r-R}\cdot\frac{\delta R}{R}$$

We have now, for a given value of $\frac{\delta R}{R}$, to find the value of R which will render this a minimum, r being a constant.

$$\therefore \frac{d}{dR}\left(\frac{1}{R(r-R)}\right)=0=\frac{-r+2R}{R(r-R)}, \therefore R=\frac{r}{2}, \text{ or } R_x=R, \text{ and } F=F_x.$$

Magnetometer. In measuring $M \div H$ by the magnetometer, the deflecting magnet is placed successively at two distances, r_1 and r_2 from the needle, producing deflections φ_1 and φ_2. And

$$\frac{M}{H}=\tfrac{1}{2}\cdot\frac{r_1^5\tan\varphi_1-r_2^5\tan\varphi_2}{r_1^2-r_2^2}.$$

Desired, the best ratio of $r_1 : r_2$; *i. e.*, that which will make $\Delta\frac{M}{H}$ a minimum. The measurements are such that δr_1 and δr_2 may be considered negligible, and $\delta\tan\varphi_1=\delta\tan\varphi_2$; thus these are the precision conditions. There are no magnitude conditions which bear on this problem. Then

$$\frac{d}{d(\tan\varphi_1)}\left(\frac{M}{H}\right)=\frac{r_1^5}{r_1^2-r_2^2}, \text{ and } \frac{d}{d(\tan\varphi_2)}\left(\frac{M}{H}\right)=\frac{-r_2^5}{r_1^2-r_2^2}.$$

$$\therefore \Delta^2\frac{M}{H}=\frac{r_1^{10}+r_2^{10}}{(r_1^2-r_2^2)^2}\cdot\delta^2(\tan\varphi).$$

To make $\Delta\frac{M}{H}$ a minimum, the fraction in the second member must be a minimum; and we wish, therefore, to find the value of $r_1 : r_2$, which will make it so. Writing, then, $r_1 : r_2 = n$, or $r_1 = nr_2$, and substituting gives

$$\frac{r_1^{10} + r_2^{10}}{(r_1^2 - r_2^2)^2} = \frac{nr_2^{10} + r_2^{10}}{(nr_2^2 - r_2^2)^2} = r_2^6 \cdot \frac{n^{10} + 1}{(n^2 - 1)^2},$$

in which we have to find the value of n to produce a minimum. Where the two variables are independent, as in this case r_1 and r_2 are independent, the following proposition may be often of service.

Let $u = f(x, y)$ where x and y are independent variables and f is such a function that it may be separated, so that

$$u = \rho(x).\sigma\left(\frac{x}{y}\right).$$

Then the value of $x : y$, which makes $\sigma\left(\frac{x}{y}\right)$ a minimum, is the same as will make u a minimum. For x cannot be expressed as a function of $\frac{x}{y}$, and, therefore, $\rho(x)$ does not enter into the determination of $x : y$ for the minimum. The same is, of course, true if the separation be made into

$$u = \rho'(y).\sigma'\left(\frac{x}{y}\right).$$

Then in the problem in hand we have to find the value of n, which will make $\frac{n^{10} + 1}{(n^2 - 1)^2}$ a minimum.

$$\frac{d}{dn}\frac{n^{10} + 1}{(n^2 - 1)^2} = 3n^{10} - 5n^8 - 2 = 0 \quad \therefore \quad n = 1.32 \text{ approx.}$$

Electro-Static Capacity. *Divided Charge Method.*—This problem presents an additional point often arising.

F = capacity of known condenser.

F_x = capacity of unknown condenser.

Q = full charge of known condenser.

q = divided charge of known condenser.

q_x = charge put into unknown condenser, but not measured. Then

$$q_x : q = F_x : F, \therefore q_x + q : q = Q : q = F_x + F : F, \therefore F_x = F\left(\frac{Q}{q} - 1\right).$$

Required the ratio $Q : q$ for greatest precision. Since charges are measured by reflecting galvanometer $\delta Q = \delta q$. By nature of the measurement F is a wholly independent quantity, so that Q is independent

of F_x, but q is conditioned by F_x and Q. But in the observations, of course, δQ and δq are independent of these conditions. Hence

$$\Delta^2 F_x = \left(\frac{dF_x}{dQ} \cdot \delta Q\right)^2 + \left(\frac{dF_x}{dq} \cdot \delta q\right)^2 = \left[\left(\frac{F}{q}\right)^2 + \left(-\frac{FQ}{q^2}\right)^2\right] \delta^2 q.$$

Substituting value of F_x and transposing gives

$$\left(\frac{\Delta F_x}{F_x}\right)^2 = \left[\left(\frac{Q}{(Q-q)\,q}\right)^2 + \left(\frac{1}{Q-q}\right)^2\right] \delta^2 q.$$

Before proceeding to find minimum, we must obtain an expression not containing q in the right-hand member, since q is a function of F_x and Q. Write $q = \frac{Q}{n}$ where n is the desired ratio $Q : q$, and substitute. Then

$$\frac{\Delta F_x}{F_x} = \frac{n^4 + n^2}{(n-1)^2\, Q^2} \cdot \delta^2 q.$$

For a minimum the value of n must make the fraction in the second member a minimum, and therefore by the proposition given in the magnetometer problem, p. 321.

$$\frac{d}{dn} \frac{n^4 + n^2}{(n-1)^2} = 0.$$

The solution of this gives $n^3 - 2n^2 - 1 = 0$, $n = 2.2$ approx.

Battery Resistance. In measuring battery resistance B by two deflections, assuming resistance box to be so exact that its errors may be neglected: —

1°, With any galvonometer for which $\delta C =$ constant, *e. g.*, a reflecting galvanometer. Call ρ_1 and ρ_2 the total resistances in circuit, inclusive of battery, when C_1 and C_2 are flowing. Then

$$\Delta^2 B = \left[\left(\frac{-\rho_1^2 \rho_2}{E(\rho_2 - \rho_1)}\right)^2 + \left(\frac{\rho_1 \rho_2}{E(\rho_2 - \rho_1)}\right)^2\right] \delta^2 C.$$

For best results we must make $C_1 = 2.2 C_2$, *i.e.*, $\rho_2 = 2.2 \rho_1$, and $\frac{\rho_1}{B}$ as small as possible consistently with avoidance of polarization effects. If $C_1 = 2C_2$ about, then $\frac{\Delta B}{B} = \sqrt{20} \frac{\rho_1}{B} \frac{\delta C}{C}$. To obtain $\frac{\Delta B}{B}$ with assigned closeness, we must use galvanometer of such sensitiveness that $\frac{\delta C}{C} < \frac{1}{\sqrt{20}} \cdot \frac{B}{\rho_1} \cdot \frac{\Delta B}{B}$.

2°. With any galvanometer for which $\frac{\delta C}{C} =$ constant, *e. g.*, a tangent

galvanometer, $\Delta B = \sqrt{2}\,\frac{\rho_2\rho_1}{\rho_2 - \rho_1}\cdot\frac{\delta C}{C}$. For best results C_1 should be as large and C_2 as small as is consistent with polarization and requisite sensitiveness. In a tangent galvanometer, using deflections of 60° and 30° for C_1 and C_2, respectively, the ratios will be about $C_1 = 3\,C_2$, *i. e.*, $\rho_2 = 3\rho_1$. Then $\frac{\Delta B}{B} = \frac{3}{\sqrt{2}}\cdot\frac{\rho_1}{B}\cdot\frac{\delta C}{C} = \frac{2\rho_1}{B}\cdot\frac{\delta C}{C}$ approx. Hence for best results with assigned value of $\frac{\Delta B}{B}$ we must make $\frac{\rho_1}{B}$ as small as is consistent with polarization and sensitiveness, and must use galvanometer of such sensitiveness that $\frac{\delta C}{C} < \frac{B}{2\rho_1}\cdot\frac{\Delta B}{B}$, and that with this value of $\frac{\rho_1}{B}$ the deflection will be about 60°. We must make ρ_2 such that the second deflection = about 30°. If deflections of 70° and 20° are used with a galvanometer having the same value of $\frac{\delta C}{C}$ at these points as the former at 60° and 30°, the value of $\frac{\delta B}{B}$ will be about 0.8 as great. Still better results may be reached by the use of a potential galvanometer, together with a current galvanometer or external circuit of known resistance.

Battery E. M. F. By two deflections.

1°. For galvanometer where δC = constant. $\Delta^2 E = \frac{\rho_2^4 + \rho_1^4}{(\rho_2 - \rho_1)^2}\cdot\delta^2 C$, and inserting $x = \frac{\rho_2}{\rho_1}$ and $E = C_1\rho_1$, $\frac{\Delta^2 E}{E^2} = \frac{1 + x^4}{(x-1)^2}\cdot\frac{\delta^2 C}{C^2}$, which will be a minimum when $x = \frac{\rho_2}{\rho_1} = 2.1$ approx. The best ratio of the currents is, then $C_1 = 2.1\,C_2$, or sensibly the same as for the measurement of B. The value of $\frac{\Delta E}{E}$ is independent of the actual value of the resistances, as it involves only their ratio $\rho_2 : \rho_1$.

2°. For galvanometer where $\frac{\delta C}{C}$ = const. $\frac{\Delta^2 E}{E^2} = \frac{\rho_2^2 + \rho_1^2}{(\rho_2 - \rho_1)^2}\cdot\frac{\delta^2 C}{C^2}$ which has no minimum, but which diminishes as ρ_2 increases, or as ρ_1 diminishes, as may be best seen by inspection after writing the fraction in the form $\frac{\rho_2^2 + \rho_1^2}{\rho_2^2 + \rho_1^2 - 2\rho_2\rho_1}$. Hence we must make ρ_1 as small and ρ_2 as large as is practicable with due regard to polarization and sensitiveness.

Rogers Laboratory of Physics, March, 1888.

FRICTION AND LUBRICATION.

BY W. O. WEBBER.

MANY of the practical engineers of to-day do not realize that a warm, well-lubricated bearing will run with less friction than a cold one. By a warm bearing I mean one whose temperature is between 130° and 160° F.

In all the oil tests I have made (some two or three thousand in number) it has been found that the co-efficient of friction is greater at temperatures below 130° F. than above that temperature, and that it then falls rapidly until a temperature of from 150° to 160° is reached, when it remains nearly constant until the oil wears out; after which the friction increases, for want of lubrication of the bearing.

The two following tests show this very clearly, and also that the temperature rises quite slowly at first, and afterward more rapidly.

C. C. Oil.			Standard Lard Oil.		
Time.	Temperature.	Co-eff. Friction	Time.	Temperature.	Co-eff. Friction.
0.000	80	.5500	0.000	80	.520
1.000	90	.5450	0.875	90	.510
1.875	100	.5125	1.625	100	.485
2.625	110	.4625	2.250	110	.450
3.250	120	.3850	2.875	120	.365
3.875	130	.2850	3.500	130	.265
4.500	140	.2000	4.000	140	.175
5.125	150	.1425	4.500	150	.125
5.760	160	.1000	5.000	160	.085
6.385	170	.0850	5.500	170	.065
7.010	180	.0730	6.000	180	.055
7.510	190	.0740	6.500	190	.055
8.010	200	.0760	7.000	200	.060
Average		.2845	Average		.263

It can also be seen that the co-efficient of friction of the lard oil decreases for the first 30° rise of temperature much more slowly than that of the mineral oil, and afterward more rapidly, but at the end it remains more nearly constant.

The tests were made to find what was the most economical kind of oil to use on the railroad by which I was employed, and were only comparative tests.

In making the tests a sample was taken from each tank-car of 4,000 gallons of black oil or kerosene, and one from every 50 barrels of lard

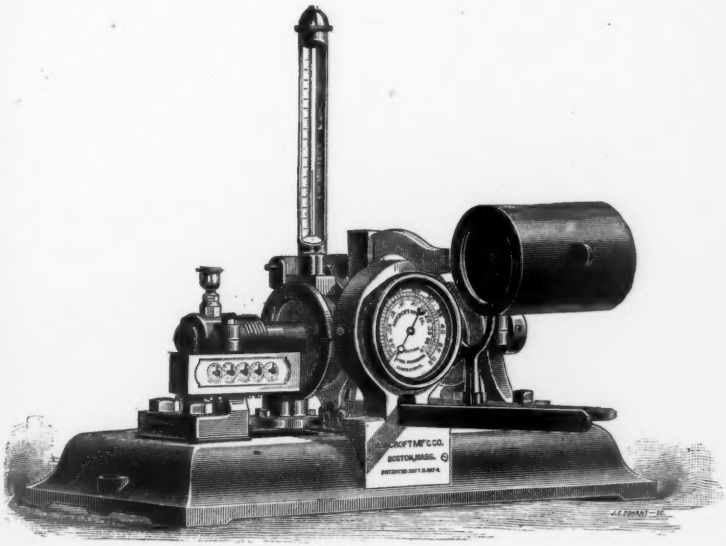


FIG. 1.

oil. The flash, fire, and freezing points, together with the gravity, were noted, and the sample was then tested on the machine for the friction and wearing quality.

The apparatus used was a journal machine, a cut of which is shown in Fig. 1.

Fig. 2 shows an end view of the machine, which consists of a journal *A*, $3\frac{1}{2}$ inches in diameter and 4 inches long, revolving in a box *B*, made in two parts, as may be seen by reference to the figure.

A part of the upper half of the box is cut away, so that only one half its surface is in contact with the journal, and is pressed down by means of the weight *W* attached to the lever *L*. To this lever is fastened a piece *D*, which presses against a projection *E*, connected to the gauge *G*, which records the friction as the journal revolves in the direction shown by the arrow.

The lower half of the box is held up against the surface of the journal as lightly as possible by the weight *W* and lever *L*, and serves merely to distribute the oil evenly over the surface of the bearing.

The oil to be tested is introduced through the oil-cup *O*, and the temperature of the bearing found from the thermometer *T*.

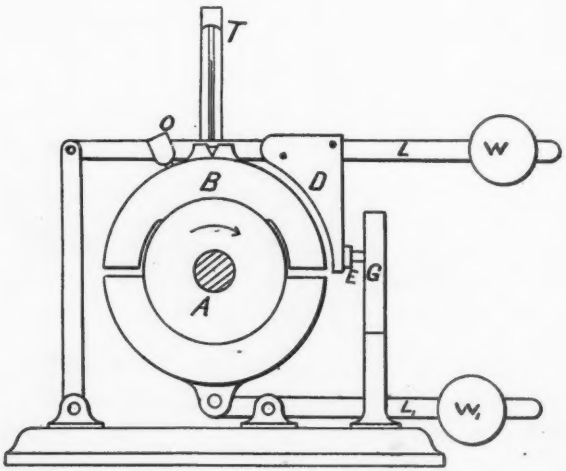


FIG. 2.

The number of revolutions is found from the counter shown in Fig. 1.

To find the specific gravity of each oil a Beaumé hydrometer was used, and the values given in the table are from the Beaumé scale.

In testing each oil on the machine a "warming-up" test was first run, after which the bearings were washed and cooled down to about 80° F., when a measured quantity of oil was put into the machine, which was then turned by hand, to be sure that the oil was evenly distributed over the bearing.

The test was then started, and the number of revolutions, temperature, and co-efficient of friction noted every half minute until a temperature of about 200° F. was reached.

Two or more consecutive tests were made with each oil, after which two were made with extra winter strained lard oil, which was considered a standard.

The total number of revolutions made with the tested oil was divided by the total number made with the standard, to get a wearing value, and the revolutions per minute made with the tested divided by the revolutions per minute with the standard, to get the lubricating value.

All the experiments made with tallow or grease of any kind in a semi-fluid or solid state were very unsatisfactory, although the tests were carefully made, and great pains taken to smear the lubricant evenly over the surface of the journal, which was turned by hand, until a perfectly lubricated surface was obtained, before starting the test.

Ordinarily good lard and tallow, free from acid, would give from 80 to 90 per cent compared with the standard, while nearly all the patent compounds gave less than 85 per cent; some running as low as 75 per cent.

The whole subject of mixed and manufactured oils was very carefully looked into, and while many samples gave very high results, others gave very poor ones; and nearly all showed the presence of free acid when tested with litmus paper, and it seemed that the nearer we kept to the simple, natural products, the better were the results obtained.

A point of great practical importance was the fire test of mineral oils in the summer months, and the cold tests during the winter.

An oil that gave a flash at from 355° to 360° F., and would not fire below from 380° to 390°, gave good results on the road; while oils that flashed and fired at lower temperatures than these, gave trouble during the summer.

An oil that will not stand a 15° F. cold test without losing its fluidity is useless in winter, for the reason that it cannot be got into the bearings on the locomotives in cold weather, although readily enough applied to those on the cars.

The appended table gives the results of some of the tests.

Kind of Oil.	Tank, Bbl., or Sample.	Gravity.	Fire Test.	Cold Test.	Initial Temp.	Final Temp.	Time run. Min.	Whole number of Revs.	Revs. per Min. Working.	Revs. per Min. Free.	Max. Co-effic. of Friction.	Av. Co-efficient of Friction.	Value, Ex. W. S. Lard Standard.	Wearing Quality.
Engine,	Bbl.,	28.5	350	40	86	206	8.625	9438.0	1093.8	1370			97.3	Fair.
Ex. W.S.Lard,	"	22.5		30	86	206	8.375	7612.0	908.6	1370			79.5	Poor.
" " "	Sample				84	204	9.125	10036.0	1100.0	1285			100.0	Excellent.
Engine,	Bbl.,	29.5	240	40	83	203	8.250	9550.5	1157.0	1260			100.1	Good.
"	Sample	30.0	380	30	83	203	7.625	7534.5	984.0	1285			82.0	Fair.
"	"	30.0	260	32	84	204	9.250	10147.0	1096.8	1285			100.4	Excellent.
"	"	30.0	250	5	84	204	7.375	7910.5	1071.9	1285			88.1	Medium.
"	"	29.0	310	10	84	204	7.125	6955.0	976.3	1270			79.0	Poor.
"	"	30.0	360	33	84	204	9.250	9797.5	1059.7	1270			96.0	Excellent.
"	"	29.0	280	30	84	204	7.375	8644.0	1172.2	1270			96.3	Fair.
"	"	30.5	270	20	85	205	7.125	7970.0	1118.2	1270			91.5	Poor.
"	"	31.0	250	25	85	205	9.250	9621.0	1046.0	1270			90.2	Good.
"	"	29.5	280	20	84	204	8.375	9448.0	1120.9	1270			98.1	Excellent.
Ex. W.S.Lard,	"				84	204	7.375	8454.5	1147.5	1446			100.0	Good.
Engine,	Tank,	29.5	310	38	85	205	7.750	8991.5	1160.2	1446			103.7	Very Good.
Cylinder,	Sample				86	206	8.375	10393.0	1239.8	1446			115.4	Excellent.
Engine,	"	29.0	310	10	86	206	7.750	8428.5	1087.0	1490			97.1	Fair.
"	"	30.5	270	20	86	206	8.500	9905.5	1165.4	1490			109.3	Good.
"	"		380		84	204	9.500	10324.0	1086.7	1497			108.4	Excellent.
"	"		310	35	85	205	8.250	9436.5	1143.8	1497			105.0	Good.
"	"		170	20	84	204	11.250	14229.5	1227.4	1490			134.0	Excellent.
"	"		250	10	84	204	8.250	9081.5	1100.8	1490			101.6	Good.
"	"		310	40	86	206	7.500	8432.5	1124.3	1497			98.8	Very Good.
Ex. W.S.Lard,	"				85	205	7.375	9943.0	1348.1	1430			100.0	" "
No. 1 Lard,	Bbl.,	23.0		40	84	204	6.250	8346.5	1334.1	1430			91.3	Fair.
Engine,	Tank,	29.5	315	40	84	204	8.750	11784.5	1346.4	1463			109.0	Excellent.
"	"	30.0	265	32	84	204	7.000	9266.0	1323.6	1453			95.6	Good.
Extra Lard,	Bbl.,	22.5		24	84	204	7.000	9024.0	1287.9	1409			93.1	Very Good.
Ex. W.S.Lard,	"	23.0		20	80	180	7.500	8063.0	1075.0	1400			100.0	Excellent.
Engine,	Tank,	29.5	290	12	80	180	7.250	7179.5	990.7	1400			90.0	"
"	"	29.0	260	12	81	181	7.750	8402.5	1160.0	1371			94.0	Very Good.
Plumbago,	Sample				76	176	6.250	7559.0	1208.1	1347			95.8	" "
Engine,	"				77	177	6.000	7069.0	1178.1	1347			91.8	Fair.
"Goose,"	"				81	181	7.000	7286.0	1040.8	1378			87.3	"
Ex. W.S.Lard,	"	23.0		20	80	180	7.250	8508.0	1174.0	1333			100.0	Good.
Tallow Comp.	"				86	186	6.500	6716.0	1032.5	1345			83.3	Fair.
" "	"				86	186	7.500	7039.5	938.5	1345			81.3	"
Plumbago,	"				85	185	8.250	5789.0	699.2	1379			63.8	Poor.
Engine,	Tank,	29.5	295	14	84	184	7.000	7919.5	1134.0	1379			94.5	Good.
"	Sample				85	185	6.750	6764.0	1003.2	1372			82.5	"
Plumbago,	"				83	183	7.500	7425.0	990.0	1372			85.8	Very Good.
No. 1 Lard,	Bbl.,	23.0		20	78	178	8.000	9126.5	1140.8	1368			102.0	" "
Extra Lard,	Bbl.,	23.0		24	78	178	8.000	8803.0	1100.0	1368			98.5	Good.
" "	"	24.0		22	82	182	7.000	7863.5	1123.3	1361			94.0	"
Engine,	Tank,	30.0	290	12	81	181	7.000	7829.5	1118.6	1340			93.5	Very Good.
"	Sample				81.5	181.5	7.750	8422.0	1086.2	1374			95.8	Good.
Green Engine,	"	29.0			80	180	7.250	7485.0	1033.0	1319			87.9	"
Ex. W.S.Lard,	"				78	178	6.250	7549.0	1216.0	1365			100.0	"
Warren,	"				77.5	177.5	5.500	4555.5	828.1	1370			64.0	Fair.
Tallow Comp.,	"				83.3	183.3	4.750	3127.5	1077.1	1371			78.2	"
Winter Car,	Tank,	28.0	280	5	80	200	8.500	9072.0	1067.2	1111			103.5	
Ex.W. S. Lard,	Sample				80	200	7.875	8436.0	1071.0	1097			110.0	
Eclipse Cyl.,	"	28.5	500+	25	82	202	7.415	8024.5	1082.1	1118			97.0	
Nat. Black,	"	30.0	280	15	80	200	7.000	7447.5	1063.9	1099			95.7	
Extra Lard,	Bbl.,	22.0		30	81	201	7.750	8264.5	1066.2	1075			98.7	
Tot.Eclip.Cyl.,	Sample	22.5	380	30	78	198	7.125	7657.0	1074.6	1086.5			95.5	
Extra Lard,	Bbl.,	22.5		20	80	200	7.875	8355.0	1060.9	1087			99.0	
Galid Lubric.,	Sample	10.0	500+	45	81	201	5.000	5249.5	1049.9	1081			80.1	
Winter Car,	Tank,	29.5	280	15	80.5	200.5	6.750	7192.5	1065.4	1071			92.3	
Ex.W. S. Lard,	Sample				83	233	29.250	31152.5	1064.9	1091			100.0	
Winter Car,	Tank,	29.5	280	15	81.5	231.5	18.375	19488.0	1060.5	1088			80.8	
Engine,	"	29.0	210	20	83	203	8.750	8301.0	948.6	1055			96.3	
"	"	29.5	250	15	84	204	8.000	8034.5	1004.2	1054			97.4	
Ex. W.S. Lard,	Sample				75	195	8.500	8299.5	975.5	1130			100.0	
Engine,	Tank,	30.0	300	13	82	202	8.500	8729.5	1027.2	1130			115.1	
Acme Engine,	Sample	28.0	230		79	199	9.000	9120.5	1013.3	1159			116.8	
Engine,	"		290	9	86	206	9.000	9010.5	1001.1	1100			105.5	
No. 1 Lard,	Bbl.,	23.0		20	86	206	8.500	8676.0	1020.6	1128			104.5	
Ex.W. S. Lard,	"	23.0		20	84	204	9.000	9180.0	1019.9	1028			107.5	
Engine,	Tank,	29.0	283	10	83	203	9.500	9423.0	992.0	1054			97.4	
Ex. W. S. Lard,	Sample				82.5	202.5	9.250	9544.0	1032.1	1054			100.0	
Black Car,	"		220	15	86	206	8.250	8313.5	1007.2	1039			92.0	
Ex. W. S. Lard,	"				82	202	8.500	8543.0	1005.0	1015			100.0	
Engine,	Tank,	29.0	300	15	82	202	8.500	8829.5	1038.7	1067			103.0	
Ex.W. S. Lard,	Sample				81.5	201.5	9.500	9781.0	1034.8	1062			100.0	
W. S. Lard,	Bbl.,	23.0		20	86	206	9.500	9634.0	1014.0	1062			98.1	

Kind of Oil.	Tank, Bbl., or Sample.	Gravity.	Fire Test.	Cold Test.	Initial Temp.	Final Temp.	Time run. Min.	Whole number of Revs.	Revs. per Min. Working.	Revs. per Min. Free.	Max. Co-effic. of Friction.	Av. Co-efficient of Friction.	Value, Ex. W. S. Lard Standard.
Ex. W. S. Lard,	Sample,				80	200	9.375	9287.0	990.60	1014.5	.575	.2550	100.00
Summer Engine,	Tank,	29.0	385		80	200	8.000	7884.0	985.40	1013.5	.570	.2930	92.18
" "	"	29.0	385		80	200	8.125	7966.5	980.45	1011.0	.560	.2990	92.37
Ex. W. S. Lard,	Bbl.,	23.0		30	80	200	9.250	9190.0	993.45	1017.0	.535	.2810	99.61
" "	Sample,				81	201	9.750	9179.0	941.40	1011.0	.500	.2744	100.00
Summer Engine.	Tank,	29.0	380		82	202	8.000	7599.0	949.94	1001.0	.555	.2856	91.84
No. 1 Lard,	Bbl.,	22.5		34	80	200	9.500	9122.5	960.25	1008.5	.535	.2760	100.69
Ex. W. S. Lard,	Sample,				80	200	8.875	8443.5	951.30	1007.5	.530	.2640	100.00
Summer Engine,	Tank,	29.0	415		80	200	7.875	7506.5	953.15	1006.5	.565	.2985	94.50
" "	"	29.0	385		80	200	8.125	7695.5	947.15	1010.0	.575	.2860	95.35
Ex. W. S. Lard,	Sample,				80	200	8.875	8512.5	959.00	1011.0	.530	.2860	100.00
Summer Engine,	Tank,	29.0	410		81	201	8.375	7988.0	953.20	1009.0	.565	.2180	96.61
Ex. W. S. Lard,	Sample,				80	200	9.250	9152.0	989.40	1013.0	.515	.2783	100.00
Summer Engine,	Tank,	29.0	395		80	200	8.375	8167.0	975.10	1008.0	.560	.2744	93.89
" "	"	29.5	385		80	200	8.000	7809.5	976.18	1005.5	.535	.2781	91.99
Ex. W. S. Lard,	Sample,				78	198	9.125	9058.5	992.72	1008.5	.505	.2555	100.00
Summer Engine,	Tank,	28.0	330		78	198	9.375	9279.0	989.81	1009.0	.535	.2660	100.06
" "	"	28.0	330		78	198	9.125	9060.0	992.83	1007.0	.535	.2672	100.06
Engine,	"	29.0	380		78	198	9.375	9279.5	989.75	1006.5	.530	.2666	101.06
Ex. W. S. Lard,	Sample,				80	200	9.375	9314.0	993.50	1015.0	.520	.2522	100.00
Summer Engine,	Tank,	29.0	400		80	200	8.750	8626.0	985.80	1012.0	.570	.2837	95.94
" "	"	29.0	398		80	200	8.875	8750.0	985.90	1012.0	.560	.2790	96.58
Ex. W. S. Lard,	Sample,				80	200	7.875	7506.0	959.44	997.0	.500	.2630	100.00
Summer Engine,	Tank,	29.0	405		80	200	6.620	6327.5	955.83	999.0	.550	.3011	91.95
" "	"	29.0	410		80	200	6.500	6239.0	959.85	999.0	.540	.2990	91.92
No. 1 Lard,	Bbl.,	23.0		20	80	200	8.500	8428.0	990.90	1075.0			90.90
Engine,	Tank,	29.5		10	80	200	8.250	8386.0	1016.50	1045.0			91.90
Extra Lard,	Bbl.,	22.5		20	81	201	9.750	10099.0	1034.80	1055.0			101.60
Ex. W. S. Lard,	Sample,				84	204	9.500	9858.0	1037.60	1062.0			100.00
Engine,	Tank,	29.0		15	83	203	8.000	8330.0	1041.20	1062.0			92.40
"	"	30.0		20	83	203	8.500	8690.0	1022.30	1074.0			93.30
Ex. W. S. Lard,	Bbl.,	23.0		15	85	205	9.500	9821.5	1130.80	1074.0			99.60
Engine,	Tank,	28.5		18	79	199	8.000	8053.0	1006.70	1074.0			89.00
Ex. W. S. Lard,	Sample,				83	203	10.000	10027.5	1002.70	1076.0			100.00
Engine,	Tank,	28.5		15	81	201	8.000	7938.5	992.30	1076.0			89.00
"	"	29.0		15	80	200	8.750	8968.0	1024.80	1048.0			95.70
Ex. W. S. Lard,	Bbl.,	22.5		10	83	203	10.000	10534.5	1053.40	1066.0			105.00
Engine,	Tank,	29.5		15	81	201	9.000	9311.0	1034.50	1063.0			97.90
"	"	29.0		10	86	206	9.500	9682.0	1019.00	1085.0			94.80
Summer Engine,	Tank,	29.00	405		80	200	6.375	6121.5	960.29	999.0	.550	.3081	90.80
Ex. W. S. Lard,	Sample,				80	200	8.000	7683.0	960.26	997.5	.500	.2595	100.00
" "	Bbls.,	22.50		28	80	200	7.625	7309.5	958.54	999.0	.500	.2607	97.47
Nat. W. Va.,	Sample,	29.00	240		80	200	6.375	6035.5	946.70	997.0	.510	.2925	88.57
Ex. W. S. Lard,	"				80	200	8.000	7757.0	969.63	996.5	.510	.2668	100.00
Summer Engine,	Tank,	29.00	400		80	200	6.500	6305.0	969.95	996.5	.560	.3083	90.65
" "	"	29.00	410		80	200	6.750	6570.0	973.00	999.0	.555	.2936	92.51
" "	"	29.00	405		80	200	7.500	7276.5	970.00	999.0	.555	.2875	96.91
Ex. W. S. Lard,	Sample,				80	200	7.875	7716.5	979.90	1010.0	.510	.2556	100.00
Engine,	Tank,	30.00	283	12	80	200	7.375	7199.5	976.10	999.0	.540	.2750	96.45
"	"	30.00	283	12	79	199	7.750	7468.5	963.40	999.5	.545	.2730	97.54
"	"	30.00	283	12	80	200	7.750	7477.0	964.60	992.5	.540	.2670	97.66
Ex. W. S. Lard,	Sample,				80	200	7.290	7240.5	993.00	1019.5	.510	.2650	100.00
Engine,	Tank,	30.00	385	17	80	200	7.250	7132.0	983.80	1017.0	.520	.2840	98.78
Ex. W. S. Lard,	Sample,				80	200	6.625	6618.0	998.92	1026.5	.510	.2790	100.00
No. 1 Lard,	Bbls.,	22.50		30	80	200	6.625	6611.0	997.98	1028.0	.520	.2820	98.89
Ex. W. S. Lard,	Sample,				80	200	6.875	6818.5	991.70	1013.0	.510	.2621	100.00
" "	Bbls.,	22.50		20	80	200	6.750	6673.0	988.58	1014.0	.520	.2700	98.77
" "	Sample,				80	200	7.250	7156.0	987.03	1007.5	.510	.2075	100.00
No. 1 Lard,	Bbls.,	22.75		32	80	200	7.250	7211.0	994.67	1009.5	.510	.2595	100.76
Extra Lard,	"	22.75		27	80	200	8.000	7810.0	976.24	1016.0	.515	.2575	100.73
Empire 15 C. F.,	Tank,	30.00	280	14	80	200	7.500	7196.0	959.46	996.5	.530	.2664	95.86
Ex. W. S. Lard,	Sample,				80	200	6.525	6441.5	987.18	1010.5	.500	.2883	100.00
Engine,	Tank,	30.00	288	17	80	200	6.375	6249.0	980.25	1009.5	.540	.2875	98.00
"	"	30.00	288	16	80	200	6.750	6632.5	984.07	1014.0	.530	.2933	100.50
Ex. W. S. Lard,	Sample,				80	200	6.875	6632.0	964.72	1007.5	.510	.2858	100.00
Engine,	"		230	9	80	200	6.275	6040.5	962.41	1012.0	.560	.3141	93.77
Ex. W. S. Lard,	"				80	200	7.000	6813.0	973.28	1011.0	.500	.2800	101.40
Engine,	"	29.75	240		81	201	6.375	5937.0	931.76	1001.0	.690	.3715	92.04
"	Tank,	29.00	390		80.5	200.5	7.375	6958.0	943.42	1006.0	.610	.3145	100.00
Ex. W. S. Lard,	Sample,				80	200	14.250	14240.5	999.39	1012.0	.450	.2314	100.00
" "	"				80	200	15.125	15044.0	994.54	1014.0	.470	.2235	102.57
Extra Lard,	Bbl.,	23.25		30	80	200	14.000	13878.5	991.30	1001.5	.510	.2278	95.96
Summer Engine,	Tank,	29.00	385		81	201	9.000	8785.0	976.10	1006.5	.510	.2677	95.49
Ex. W. S. Lard,	Sample,				81	201	10.000	9710.5	971.05	1009.0	.510	.2650	100.00
" "	"				80	200	9.500	9208.0	969.20	1012.0	.525	.2805	100.00
Summer Engine,	Tank,	29.00	390		80	200	8.370	8106.0	967.88	1010.0	.530	.3024	93.94
No. 1 Lard,	Bbl.,	23.00		28	80	200	8.370	8081.5	964.97	1006.5	.520	.2988	93.66
Summer Engine,	Tank,	29.50	390		80	200	8.125	7745.0	953.23	1012.0	.560	.3068	91.23
Ex. W. S. Lard,	Sample,				80	200	9.450	9144.5	966.99	1008.0	.520	.2744	100.00
Summer Engine,	Tank,	29.50	385		80	200	8.000	7654.5	956.80	1009.0	.560	.2990	91.32

NOTES ON ASSAYING OF LEAD, SILVER, AND GOLD.

BY FREDERICK W. CLARK, S.B

CHAPTER II.

LEAD ASSAY.

THE principal sources of lead are,—

Galena PbS	86.6	per cent	lead.
Cerussite $PbCO_3$ . . .	77.5	"	"
Minium Pb_3O_4 . . .	90.	"	"
Anglesite $PbSO_4$ . . .	68.3	"	"
Pyromorphite ($3\ Pb_3P_2O_3 + PbCl$)	76.3	"	"

The results of the assay of lead by the dry method are inaccurate, owing to its volatility (which is increased by S), its tendency to slag off (which is promoted by the presence of As, Sb, Zn), and by reason of contamination with other metals (Cu, As, Bi, Sb, Ag, Au). Kerl states that 85.25 per cent out of the 86.6 can be obtained from pure galena, but in poor ores the loss is much greater.

Zinc is partly volatilized and partly goes into the slag. Arsenic goes partly into the lead, partly volatilizes, but most of it forms a speiss with iron. When present the lead button is always brittle. A large part of the antimony present goes into the lead. Copper divides itself between the lead and the slag. Silver and gold pass into the lead. Assays by the wet methods will be from 3 to 10 per cent higher (reckoned on the Pb contents) than by the dry method. For instance, a galena giving 65 per cent wet will perhaps yield 62 to 63 by dry methods. One giving 16 per cent wet will yield 14 to 15 per cent by dry assay.

The dry assay of lead is in general use at smelting establishments for assaying ore and furnace products. Lead ores are always bought and sold on basis of fire assay.

In the assay of lead the object is to flux, by means of the alkaline carbonates, the silica and earthy portions of the material, to reduce the lead from its combinations by means of carbon and metallic iron. The slag formed serves as a cover to the reduced metal. To further prevent volatilization and to modify the ebullition caused by the escape of CO_2 and CO, a cover of salt is generally used. Wrought-iron crucibles are generally used in England instead of adding iron in the earthen crucibles, the practice in this country.

The condition of the ore, whether it is sulphuretted or oxidized, pure or containing other metals and earths, will determine the proportion of fluxes used.

Five or ten grams are usually taken for assay. For muffle assay the Colorado A A & A Battersea, or the corresponding sizes of Denver crucibles, are generally used. For the pot furnace, with 10 grams ore, the Battersea U or V, or the Hessian Small 5 or Centimeter are of proper size. Covers are used in the pot furnace, but not in the muffle.

The following charges are for 5 grams ore. If 10 grams are used, double the quantity of flux given. Use same number of nails, but of larger size :—

	Galenas.	Calcareous or Zincy. §	Oxide and Carb.	Slag.	Cupriferous.	Antimonial.
Ore, grams.	5	5	5	5	5	5
Soda "	15	15	10–15	15	15	15
Potash "	. . .	5–10	5	0–5	. . .	5–10
Nails	3	1–3	. . .	1	4	3
Borax, grams.	4–6	5	4	6	6	10
Argol "	4	4	6	6	. . .	4
Sulphur "	. . .	. . .	. . .	. . .	0–1†	. . .
Silver "	. . .	. . .	. . .	½–1*	. . .	. . .
Nitre "	. . .	. . .	. . .	. . .	. . .	1–2‡
Salt "	cover.	cover.	cover.	cover.	cover.	cover.

Where many assays are to be made a mixture of re-agents may be prepared, which will serve for nearly all ores. As, for instance :—

Carb. Soda	2 pts.
Carb. Potash	1 "
Argol	½ "
Borax glass or calcined borax	¼ "

Mix thoroughly, and pass through 30 to 40 mesh sieve. Use 10 to 20 grams for 5 grams ore ; add nails, etc., as required. Add silver in slags, and use salt cover.

*The weight of silver used must be deducted from the lead button obtained.

†Used with good results on sulphate of lead residues containing up to 20 per cent Cu. Object is to dilute copper sulphide and precipitate the lead sulphide with metallic iron. The copper sulphide remains for the most part with the slag.

‡If much antimony be present the fire assay should not be used.

§If much lime is present add 2 to 3 grams oxide iron (ruddle).

If borax glass is used, take half above weights of borax.

A proportion recommended by Mr. F. D. Chase (used at Pueblo Smelting Works) is :—

Soda	15 pts.
Borax (dried)	1 "
Argol	3 "

Add 1 to 3 horse-nails, and salt cover. Use dry-cup full (10–15 gr.) for 5 gr. ore.

Another recommended by Mr. John Duff, is :—

Bicarb. Soda	2 pts.
Carb. Potash	$1\frac{1}{3}$ "
Borax	1 "
Starch	1 "

Sift through 40 mesh, mix intimately, and use dry-cup full to 5 gr. ore. Add 1 to 4 nails, according to amount of sulphur present.

Mr. Geo. Faunce, of the Pennsylvania Lead Co., recommends the following for lead slags :—

Slag	10 gr.
Black Flux	40 "
Silver	1 "
Borax	10 "

Proportions recommended by Percy (Mett. Lead, pp. 111–112) are as follows,— galena assayed in wrought-iron crucible, and carbonate and phosphate in earthen crucibles. Weights are given in grains (480 gr.=1 oz. troy = 31.1 grams):—

	I.	II.	III.	IV.	V.
Ore	500	500	300	300	500
Carb. Soda	500	350	400	350	500
Borax		150	30	30	30
Argol	50	50		100	100
Charcoal			20		

I. For pure galenas.
II. For poorer galenas and rich galenas.
III. and IV. For phosphates.
V. For carbonates.

DIRECTIONS FOR CONDUCT OF ASSAY.

Weigh out and place in crucible the soda, potash and reducing agent (and borax if used as glass), then weigh the ore carefully and place on top. With a spatula thoroughly mix the charge and insert the nails, point down,

taking care they rest on the bottom of the crucible. Sprinkle the salt ½ to ¼ inch deep on top, and borax, when crystallized, is dropped on top of all. The cover is placed on the crucible and it is ready for the furnace.

A still better way is to mix two thirds of the flux with the ore, and place the other third on top. If you have several crucibles, mark them in any convenient way with ruddle, ochre, limonite, etc.

The assay may be made either in a pot furnace or in a muffle furnace.

In crucible furnace the fire should be built with shavings, wood, and a little charcoal and coke. Let it burn up well, then add a little coke to dampen fire, taking care to have about four inches of coke on the grate bars.

Place the crucible, with covers, in the furnace, and fill around them with coke; admit the draught, and bring up to fusion in 5 to 10 minutes. Maintain heat until the contents of crucible are in quiet fusion, then increase heat for a few minutes. Take out the crucible, remove the nails with the cupel tongs, tap gently, and set the crucible aside to cool; or better, pour the contents into an iron mould. If the contents of crucible threaten to boil over, moderate heat by closing lower door, taking cover off furnace, removing cover of crucible, or lifting it somewhat out of the coals. The time of assay should not exceed 20 to 25 minutes. If the fusion is made in the muffle, the muffle must first be brought to a bright red heat, then crucibles are put in and doors closed. A bright red heat is maintained for 20 minutes, or till boiling has mostly subsided, then raised to a yellow heat for 10 minutes, crucibles taken out and poured or cooled.

A brittle button shows presence of sulphur, arsenic, or antimony; a bright coating between button and slag, too low heat and imperfect decomposition; a brilliant lead button and vitreous slag, too high and long continued heat.

An assay and duplicate should agree to within ½ to 1 per cent. If any metal adheres to the nails when taken from the crucible, it indicates that the reaction is not quite finished, and the crucible must be returned to the furnace. In presence of much Cu, Zn, As, Sb, or Bi, the dry assay of lead should be rejected.

Covers are used in the pot furnace to equalize heat and prevent fuel from falling into the crucible.

In the muffle furnace, bring the muffle to a good, clear red heat, place the crucibles without covers, prepared in the same manner as for the pot furnace, in the muffle, with a little charcoal in front of the outer row; close the door, and heat for 20 to 30 minutes, when contents should be ready to pour.

REMARKS.

To obtain the best (highest) results in the fire assay of ores and slags, considerable practice is required, as the heat, time, fluxes, etc., have considerable effect on the result of the assay. A more equable temperature and uniform heating is obtained in a muffle, and as a rule, better results are obtained. Instead of marking the crucibles, the assayer may work from right to left, and know the assay from its position in the furnace mould, etc. That is, the first assay put in is No. 1, the next to the right of No. 1 is No. 2, then No. 3, etc. If in several rows, then the left one of row two follows the last one (at the right) of row one, etc.

It is best, on account of the saving in time, to use a prepared flux, and measure the amount required, increasing the usual amount if much lime, zinc, clay, etc., be present, and adding a little nitre if arsenic or antimony be present.

The iron used should be of good quality,—that is, free from slag, etc.,—and low in carbon, so that no skeleton of carbon, slag, etc., is left on the completion of the assay, as little globules of lead are caught in it and lost. Sheet-iron, bent to conform with the walls of the crucible, and projecting above the rim, may be substituted for the nails. The loss in the lead assay is caused in part by the volatility of the lead sulphide, which may sublime before the charge is well melted. On this account the assay should never be subjected to a long low heat. Moderately high heats and short time give the best results.

A large excess of carbon is used to keep the action in the crucible, strongly reducing to prevent the lead from entering the slag as silicate. The metallic iron decomposes the sulphide and oxide, and the resulting sulphide and oxide of iron dissolve in or combine with the slag.

GOLD AND SILVER ASSAY.

OCCURRENCE.

Gold is found in the native state in alluvial deposits and gravel beds, in quartz ore veins, and other rock matter. It is commonly associated with iron, copper, and arsenical pyrites, and more rarely with tellurium. Native gold is rarely pure, but contains from 1 per cent to 40 per cent of silver.

The sources of silver are numerous. Silver ore may be divided into two classes (Kustel),—(A) real silver ores, and (B) argentiferous ores. In the first class, the silver occurs as a definite compound, with sulphur, arsenic, antimony, etc., as silver gance (Ag_2S 87.1 per cent Ag), horn silver (AgCl), stephanite ($5\ Ag_2S + Sb_2S_3$). In the second class, the silver is associated with another metal or metals, and is often of secondary

importance. Galena, blende, pyrites, and cerussite are the most common argentiferous minerals. Silver ores are rarely entirely free from gold.

There are two general methods for the assay of gold and silver ore; viz., the scorification assay and the crucible assay. *Any ore can be assayed by either of these methods.* The assayer selects that one best adapted to his ores.

SCORIFICATION ASSAY.

The scorification assay is the simplest and surest method, and universally applicable to all ores. The objection to it is the smallness of the quantity treated, and the time required for assay. The ore is mixed in the scorifyer with a certain amount of granulated lead and borax, the quantities varying with the nature of the ore, and is then subjected in the muffle to a high heat, with exposure to the air. The lead is partly oxidized, and the litharge combines with the gangue of the ore, forming easily fusible silicates. The gold and silver is absorbed by the molten lead, while sulphur and the volatile metals are driven off. The borax dissolves the oxides and gives liquidity to the slag. The *modus operandi* of the assay is as follows: Weigh out the finely crushed ore into the scorifyer, and mix with it thoroughly one half the charge of granulated lead; cover mixture with the balance of the lead, and drop the borax on top. Three distinct periods are observed, as follows: —

(1) *Roasting and Fusion Period.* Place the scorifyer in the *red-hot* muffle, and close the door. Bring to fusion as quickly as possible (5 to 15 minutes). The ore will now be seen floating on the bath of molten lead. Admit air to the muffle and immediately the lead begins to oxidize (fumes arise from the scorifyer, due to sulphur and volatile metals), and the litharge formed attacks the gangue and forms a ring of slag around the scorifyer. This ring must have smooth edges, and surface free from lumps. If this is not the case, either the heat is insufficient or the quantity of flux used is not enough. The time required for the roasting and fusing is from 10 to 20 minutes.

(2) *Scorification Period.* The heat is gradually lowered as the oxidation progresses; litharge forms freely, carrying with it oxides of other metallic impurities, and coming in contact with the sides of the scorifyer takes from it the material necessary to form a very basic silicate of lead, which forms a receiver for all the non-volatile metallic impurities in the ore; and when the slag completely covers the lead bath the scorification is finished.

(3) *Liquefaction Period.* Close the door and raise heat for 5 or 10 minutes to liquefy slag, then remove and pour into mould. The whole

operation takes from 40 to 50 minutes. (If lumps of scoria appear on the slag surface add more borax, or a few grams of litharge.) The lead is detached from the slag, hammered into cubical form, and if soft and malleable, is ready for the next stage or cupellation. If much copper is present a second or third scorification, with fresh additions of lead, may be necessary. The borax gives liquidity to the slag at the commencement of the operations, by dissolving oxides as they are produced, and combining with the gangue. When the slag is liquid it is continually thrown to the sides of the scorifyer. If semi-fluid particles float on the surface of the lead it is an indication that borax is needed. The proportion of lead and borax necessary for a scorification varies exceedingly, and ought to be greater the more difficultly fusible the ore. Borax is especially useful when lime, zinc, arsenic, antimony or barium is present. The following table, from Kerl's Assayers' Manual (Wahl.), pp. 134–5, gives the proportions to be used with ore one part: —

SUBSTANCE.	Pts. Test Lead req.	Per cent Borax Glass.	REMARKS.
Mill Tailings	12–15	to 15	After scorifying two portions of $\frac{2}{10}$ A. T., combine buttons and cupel.
Antimonial Silver	32	300	Take $\frac{1}{20}$ A. T.
Antimonial Ores	16	200	Take $\frac{1}{20}$ A. T.
German Silver or China Silver,	20–24	to 40	
Arsenical Ores	to 16	to 50	High temp. in scorifying.
Galena, Pure	6	0–15	
Galena, Silicious Galena, Zinciferous	11	20–30	
Lead, Speiss	10–20	15–25	
Lead Matte	9–20	12–25	
Lead Matte Nickeliferous	11–14		
Bronze	20–24	20–25	Scorify several times.
Milling Silver Ores	12–15	10–15	
Iron (cast-iron)	8–12	2–3	First oxidize in muffle or with HNO_3.
Copper	18–20	to 5	
Jewellers' Sweeps	8–9	to 20	
Hearth Bottoms	8	10–20	
Gun Metal	20–24	20–25	
Cobaltiferous Ores	20	15–20	
Nickeliferous Ores	20	15–20	
Cupriferous Ores	10–20	10–15	
Copper Matte	12–15	10–15	
Brass	20–24	15–20	
Furnace Deposits	12–14	10–15	
Slags	12–15	10–15	
Copper Oxide	8–10	1–10	
Zinciferous Ores	10–16	15–25	High temperature.
Angentiferous Zinc	16	16	Take $\frac{1}{20}$ A. T.
Stanniferous Ores	20–30	15–25	Scorify several times.
Argentiferous Tin	16	16	Oxidize with HNO_3 Use $\frac{1}{20}$ A. T.

For most ores twelve parts of test lead and .25 parts borax answers very well, and a good proportion for general use, is,—

Ore	$\frac{1}{10}$ A. T.
Lead	35 grams.
Borax	1 gram.

If the ore is refractory, one half the quantity ($\frac{1}{20}$ A. T.) may be taken, or the lead doubled in quantity, and borax added from time to time as required.

For calcareous ores use 16 parts test lead and 15 per cent borax, and if surface is not smooth add a few grams of soda carb.

For teluride ores use 32–100 parts lead and 25 to 50 per cent borax glass.

When gold is to be determined accurately, from three to ten portions are weighed out and scorified and cupelled separately. The scorification assay usually gives better results than the crucible method on complex ores when much sulphur and base metals are present. When ores are very poor a number of buttons are combined and re-scorified. As the loss of gold and silver is much less by scorification than in the subsequent operation of cupelling, it is best to carry this operation as far as possible. A button weighing 10 to 20 grams is a convenient size for cupellation.

During the roasting and fusing period the color of the fumes gives some indication of the composition of the ore. Sulphur gives clear gray vapor; zinc, blackish vapors and a brilliant white flame, also causes ebullition and consequent loss; arsenic, whitish gray vapors; and antimony, fine red vapors. *Observe scorifyer after pouring.* Lead colors the interior of scorifyer a lemon yellow; iron, reddish brown; copper gives green (light to very dark); Te gives blood-red (Brown); Mn, brownish black.

CUPELLATION.

This operation differs from scorification, in that the litharge formed is absorbed by the cupel, leaving the lead surface always uncovered. The *modus operandi* is as follows: The cupels are slowly heated until they acquire the temperature of the muffle (bright red). Place the buttons obtained from the scorification (after freeing from slag and hammering to cubical form) upon the hot cupels, close the door, and bring to fusion quickly. As soon as surface is clear open the door, and the lead immediately begins to oxidize. Most of the oxide is absorbed by the cupel; a little escapes from the muffle, as fumes of carbonate of lead. As silver is sensibly volatile it is best to keep the heat rather low. When the fumes

rise about half the height of the muffle, the metal is luminous and clear, and little crystals of litharge (feathers) form on that side of the cupel nearest the door, the heat is about right. If the heat is too low, or too much copper or other metal is present, the assay will "freeze," and the operation come to an end. The cupel must then be removed, the button wrapped in lead foil and placed on a fresh cupel. These assays are usually low. If the cupel is too compact the litharge will form a ring about the button, as in the scorifyer. In this case remove and cool, wrap in lead and place on fresh cupel. If copper be present add more lead, or scorify again with addition of lead. When the last of the lead separates, and the button is not smaller than a pin-head, there is a brilliant play of colors, then the button becomes dull; this is known as the "blick," "brightening," "fulguration," or "coruscation." Let stand a moment and gradually withdraw from the muffle, to prevent "spurting" or "vegetating."

The button should be bright, well rounded, and separate easily from the cupel. A cupel absorbs about its own weight of litharge. The button of silver is now seized with a pair of nippers and the bottom brushed with a stiff brush, to free from adhering cupel bottom, etc., and is then weighed and allowance made for silver contained in the lead used in the assay. If gold is to be determined the button is now dissolved in equal parts of strong C. P. HNO_3 and water,— best in a test-tube or parting flask. Decant off the solution; the gold is left as a spongy mass. Treat again with strong HNO_3. Then wash with hot water, twice or thrice. Fill test-tube with water, place a No. 8 porcelain crucible, or, better, a dry cup over mouth of test-tube and invert. The gold will settle into crucible. Raise tube to edge of crucible and quickly slide off without disturbing the gold. Decant water from crucible, dry carefully, then heat to redness and weigh. When several assays of the same ore have been made, it is customary to dissolve all the silver buttons (after weighing) at once. If less than two and one-half parts silver to one of gold is present, the button will not dissolve in acid. It must then be fused on charcoal, with pure silver, or wrapped in lead foil and cupelled. The latter is the best way. Instead of porcelain crucibles the "dry-cup," made of fine clay, may be used. This is porous, and absorbs the last of the water. Dry-cups should be heated in a muffle, not over a lamp.

Pure lead colors cupel straw yellow, verging to lemon yellow. *Copper* gives a gray, dirty red, or brown. *Iron* gives black scoria at beginning, and is left on surface of cupel. *Zinc* causes boiling, and consequent loss; also gives a luminous flame. *Antimony* gives yellow scoria, and cracks the cupel.

CRUCIBLE ASSAY.

The advantage of this method is that a considerable quantity of material may be operated upon, and the time required is usually less than for a scorification.

The disadvantage of it is, that with some complex ores, containing much S, As, Sb, Cu, Te, etc., it is difficult to obtain all the gold and silver contents alloyed with a proper amount of lead, and sufficiently pure for cupelling, without an intermediate scorification. The results of the crucible assay are not generally as high as the scorification assay if arsenic and antimony or large amounts of other base metals are present; but for silicious, oxidized, and calcareous ores, it is recommended for both silver and gold.

In nearly all crucible assays the lead necessary for the collection of the gold and silver is obtained by the action of reducing agents upon oxide of lead.

The crucible assay may be divided into two general systems, either of which may be used for the determination of gold; but in the silver assay if sulphur is present in the ore, it must be completely oxidized by an excess of litharge or by the addition of nitre. In the first system a large excess of litharge is used, part being reduced and part going into the slag. All base metals, except the required lead, are oxidized and dissolved in the slag. This assay is quickly made, but different ores require considerable modification of reducing and oxidizing agents.

In the second system, only enough litharge is used to furnish the required lead. All base metals, except lead, remain combined with sulphur or combined in the slag, or in the case of As and Sb partly combine with iron and partly volatilize. This assay requires a longer time, but offers the following advantages:—*

(1) The right quantity of lead may nearly always be obtained at once.
(2) It requires slight modification for different ores.
(3) The button is never much contaminated with copper.
(4) The crucible is not much attacked.

FIRST SYSTEM OF CRUCIBLE ASSAY (LITHARGE-NITRE ASSAY).

This is the usual method of assay with the crucible, but different ores require considerable variation in the proportion and amounts of fluxes used. If much sulphur is contained, it reduces an amount of lead from the litharge that is very inconvenient to cupel; therefore we oxidize the

*Aaron's Assaying of Gold and Silver.

sulphur by adding nitre to the crucible charge in sufficient amount. The sulphates formed are dissolved in the alkaline slag. Most of the base metals are oxidized, and enter the slag as silicates.

If much peroxide of iron or manganese is present in the ore, an extra amount of reducing agent must be added; for when the peroxides are treated in presence of silica and carbon, an equivalent of oxygen is given off, which combines with the C present and escapes as CO or CO_2. So we must have present in the crucible not only sufficient carbon to reduce a proper amount of lead, but enough more to satisfy the O given off.

The action in the crucible may be described briefly as follows: The silica and base metal oxides of the ore combine with the soda and litharge present to form easily fusible silicates; the borax dissolves the base metal oxides and gives liquidity to the slag; the carbon and sulphides act upon the litharge, forming lead and sulphates; the reduced lead showering down through the charge and stirred up by the escaping CO_2 of the soda carb., combines with the gold and silver present, and finally sinks to the bottom of the crucible. The fluxes are chosen so as to give an easily flowing slag and a lead button of convenient size for cupellation. The more abundant the base metal compounds the more flux must be added.

All ores may be divided into three classes; viz., (a) those requiring a reducing agent; (b) those not requiring a reducing agent; and (c) those requiring an oxidizing agent.

To the first class belong silicious and oxidized ores containing little or no sulphur.

To the second class belong ores containing about ten per cent pyrite or a corresponding amount of other sulphur compounds so that when fused with an excess of litharge a convenient amount of lead (15–25 grams) for cupellation will be reduced.

To the third class belong all ores which contain sulphur to such an amount that when fused with an excess of litharge, an amount of lead will be reduced that exceeds 30 grams in weight, *i. e.*, a convenient amount for cupellation.

The assayer soon learns to judge by its appearance to what class an ore belongs, but the beginner must make a test to learn the reducing power of his ore, the oxidizing power of the nitre, and, in some cases, the oxidizing power of the ore.

The reducing power of the ore is found by fusing one or two grams of ore with say 50 grams of litharge, 20 grams soda, and a salt cover.

The oxidizing power of nitre is determined by fusing: —

Nitre	1 gram.
Ore or reducer	2 grams.
Litharge	50 "
Soda	20 "
Salt (cover).	

Weigh resulting lead button, and knowing amount that two grams of ore would have reduced if no nitre was used, the difference will be the oxidizing power of one gram of nitre. It is usually about four grams lead for one of nitre.

Litharge usually contains some silver, and the amount must be ascertained and allowed for in the assay.

All ores may be reduced to the first class by expelling the sulphur and volatile metals by subjecting the ore to heat in a current of air. This is done in the muffle in a shallow iron, or fire-clay dish. Begin with an extremely low heat, to avoid loss by spitting, and raise gradually to a dull red, stirring at frequent intervals to avoid sintering. When glowing has ceased and no SO_2 can be detected the roasting is finished, and the ore is said to be "sweet." If much As, Sb, or Cu is present after the SO_2 is apparently expelled, add an equal bulk of charcoal and heat again. This is to decompose the sulphates, arsenates and antimoniates.

Carbonate of ammonia is useful to decompose sulphates (as Cu SO_4) formed in the roasting. Sulphate of ammonia is formed and volatilized. Dish should be covered after adding it. If ore tends to cake during the roasting, mix silica with it. The operation of roasting is not often performed, on account of the time required and liability of loss by spitting and volatilization.

It is preferable to vary the litharge, nitre, and argol, as required by the ore in hand. The more refractory or sulphuretted the ore, the larger the amount of litharge and nitre necessary. The presence of considerable peroxide of iron or manganese necessitates the addition of more argol in the absence of other reducers (C, S, etc.).

Proportion of Fluxes. Mitchell gives one general formula suited for all ores, as follows: —

Ore	1 part.
Soda	1 "
Litharge	5 parts.

Reducing or oxidizing agents are added as required by the ore. Borax is added if the slag is not sufficiently fluid, and a cover of salt may be used if desired. The objections to these proportions are, the expense of

litharge and the rapid destruction of the crucible by the excess of litharge.

A considerable latitude is allowable in fluxing ores, and much depends upon the judgment of the assayer. For the three classes of ore (p. 30) the following charges are given: —

For silicious ore a good charge is: —

	*Silver Assay. A or F Battersea.	Gold Assay. S or G Battersea.
Ore	$\frac{3}{10}$–$\frac{1}{3}$ A. T.	1 A. T.
Litharge	30 grams.	80 grams.
Soda	20 "	40 "
Borax	5–10 "	15 "
Argol	1 "	2 "
Salt (cover).		

If Fe_2O_3 or MnO_2 be present in quantity, add more argol.

For slightly sulphuretted ores: —

	Silver Assay.	Gold Assay.
Ore	$\frac{1}{3}$ A. T.	1 A. T.
Litharge	40 grams.	100 grams.
Soda	20 "	40 "
Borax	5–10 "	20 "
Argol	$\frac{1}{2}$–0 "	$\frac{1}{2}$–0 "
Salt (cover).		

For heavily sulphuretted ores: —

	Silver Assay.	Gold Assay.
Ore	$\frac{1}{3}$ A. T.	1 A. T.
Litharge	50–80 grams.	100–200 grams.
Soda	20 "	40 "
Nitre	2–20 "	6–60 "
Borax	10–20 "	10–30 "
Silica or Glass	0–10 "	10–30 "
Salt (cover).		

A charge commended by Aaron for sulphurets is: —

Ore	1 part.
Litharge	8 parts.
Soda	2 "
Borax	2 "
Nitre	2 "

* There is no objection to using 1 A. T. ore in a silver assay, except the matter of convenience of working with smaller quantities; nor, on the other hand, is there any reason why the gold in $\frac{1}{8}$ or .3 A. T. cannot be satisfactorily determined in many ores, provided the balance can be depended upon to weigh accurately to $\frac{1}{100}$ mg.

"Melt gently. When bubbling ceases under a good red heat, add $\frac{1}{6}$ part charcoal in small lumps.

"In this charge the nitre is sufficient to oxidize all the sulphur in concentrated pyrites. It is important that the slag should be thoroughly oxidized, retaining no trace of sulphurets."

In this system of assay iron is not necessary. If used, it is liable to throw down too much lead. When Cu, Sb, As, Zn, etc. are present a large amount of litharge is desirable to thoroughly oxidize them, so that they shall go into the slag rather than into the lead. When fusions are made in the muffle, this system offers the advantage of smaller crucibles to hold the necessary amount of flux.

For tellurium ores, use large amount of litharge (150–250 grams) and usual amount of other fluxes.

The button of lead alloy obtained by the crucible fusion is cupelled as in the scorification assay. (See pp. 27–29.)

SECOND SYSTEM OF CRUCIBLE ASSAY (SODA-IRON ASSAY).

For silicious ores this differs little from the first system, but for sulphuretted ores there is a radical difference. In these we make no attempt to oxidize the sulphur, but absorb all the base metal sulphides in the alkaline slag, and rely upon metallic iron to precipitate the metallic lead. The results on heavily sulphuretted gold ores compare very favorably with the litharge-nitre assay.

For silicious ores (dry ores) : —

	Silver Assay.	Gold Assay.
Ore	$\frac{1}{3}$ A. T.	1 A. T.
Soda	30 grams.	60 grams.
Litharge	20 "	30 "
Borax	10 "	15 "
Argol	1 "	2 "
Salt (cover).		

For sulphuretted ores : —

	Silver Assay.	Gold Assay.
Ore	$\frac{1}{3}$ A. T.	1 A. T.
Soda	60 grams.	100 grams.
Litharge	20 "	30 "
Borax	10 "	20 "
Nails (10d)	4	4
Salt (cover).		
Silica.		

Melt to quiet fusion; let stand in furnace for ten minutes or so, and pour. It is well to seize crucible with the tongs when quiet fusion is reached, and give contents a rotary motion. The nails will sometimes stick to the sides of crucible, and this treatment will send them to the bottom, where they are needed.

Aaron gives the following general formula for assays by second system (Part I. p. 53):—

Ore	1 part.	Melt, and leave in fire 20 minutes after fusion.
Litharge	1 "	
Soda	3 "	
Borax	$\frac{1}{2}$ "	
Sulphur	$\frac{1}{10}$ "	
Flour	$\frac{1}{10}$ "	
Glass.		
Iron (3 nails).		
Salt (cover).		

"None of the substances will do any harm, even if not required. If the ore contain much sulphur, that may be omitted. If quartz ore, glass may be left out. If much iron oxide, or copper oxide be present, increase flour and sulphur. For pure red oxide of iron, or black oxide of copper, use 50 per cent (of ore used) sulphur and 40 per cent flour. Little copper gets into the button if enough sulphur is present."

Aaron recommends this system for gold-bearing sulphurets.

REMARKS.

It is quite impossible to give fluxes best suited to all cases, but by keeping in mind the action of the fluxes, the assayer will soon arrive at the proper flux for the ore in hand. There is the widest diversity in different localities and with different assayers.

Duplicate assays of silver on most ores should agree to within one ounce per one hundred. Gold assays should agree more closely than silver. Unless the ore contains free gold, assay and duplicate should not differ more than $\frac{1}{10}$ ounce per ton.

In case of a difficult ore it should be assayed by different methods,— as the scorification with varying amounts of lead, the crucible with much litharge, and much soda with little litharge, by roasting previous to fusion, etc. The highest results should be taken, as a rule.

The cupellation of the lead button of the crucible assay is treated precisely as described in the scorification assay (pages 27–29). If "dry-

cups" or "annealing-cups" (porous clay) are used for collecting and drying the gold, there is little danger of loss when the moisture evaporates. With glazed porcelain crucibles a little spitting will occur, unless special care is taken in heating the crucible. Silver and gold assays should be weighed directly — never by difference; nor should a weight much exceeding one gram ever be allowed on the delicate assay balance.

For the accurate determination of gold, an assay ton of ore is as little as should be used; and on very low-grade ores, several portions of 1 A. T. each should be taken, the buttons scorified and cupelled on one cupel.

PREPARATION AND ACTION OF ALIZARINE ASSISTANT.

BY CHARLES B. KENDALL, S.B.

THE literature concerning alizarine assistant and the receipts given for its preparation are of a very confusing and contradictory nature. In view of this fact the following investigation was made, to determine the best proportion of acid to use, and, as far as possible, the effect given by the differently soluble portions of the oil so produced.

The action of sulphuric acid on castor oil gives water soluble and insoluble bodies, mixed with more or less neutral fat. The composition of these bodies has been examined into by Liechti and Suida.[1] To which of them the effect of the assistant in alizarine dyeing is due, or, if it be due to a mixture, in what proportions they should be combined, has not been so thoroughly investigated. Lubianeff[2] made an investigation somewhat in this line, but he did not compare the assistants prepared by different receipts, and judging by his article, he used but one proportion of acid in the preparation of the assistant. He divided his assistant into water soluble and insoluble bodies, and investigated the colors produced by each, and by mixtures. He found that the soluble portion gives purity and fire, and the insoluble portion depth and evenness to the color. As to the presence of neutral fat, he concludes that it may be present, and may influence the lake, but above a certain per cent it is injurious. His conclusions in this regard do not agree with those of Müller-Jacobs.[3]

A series of four experiments was undertaken to gain further information regarding the action of the assistant. The castor oil used was the quality designated as number three, and was of good color. A

[1] Berichte der chem. Gesell. 1883, 2,453.
[2] Dingler, 262, 36. [3] Dingler, 251, 547.

small amount of this oil was placed in a stone crock, and treated with *one fourth* of its weight of strong sulphuric acid. The crock was placed in cold water, and precautions taken to insure a low temperature. The acid was added at intervals, and well stirred in. Finally the mixture was allowed to stand over night. It was then washed once with water, and divided into two portions. One of these was washed farther with salt and water, and then finished. It was neutralized with ammonia until a drop gave an emulsion with water easily cleared by a small amount of ammonia. The second portion was treated with four times its volume of water, and after the liquids had separated into layers, the water was siphoned off. In this case no water soluble bodies could be obtained, although the treatment with water was repeated. This oil gave, even in alkaline solutions, a permanent emulsion. It gave a poor, dull red. Analyses were made as follows: —

WATER.	TOTAL FAT.	NEUTRAL FAT.	SULPHUR.
13.29 %	83.89 %	34.22 %	0.11 %
14.08	83.89	33.38	
12.96			

In the next experiment the oil was treated with *one half* its weight of acid in exactly the same manner as described in the preceding experiment. Twenty-six hours were consumed in introducing the acid. On separating this oil a solution of the water soluble portion was obtained This was easily thrown out of the solution by the addition of salt. By this treatment an oil was obtained much lighter in color than the insoluble one. Before separation a small portion of the oil was finished as in practice. This gave a clear oil of a very good amber color. It contained: —

WATER.	TOTAL FAT.	NEUTRAL FAT.	SULPHUR.
37.45 %	54.51 %	1.71 %	2.02 %
39.02	54.38		1.92

This gave the best red obtained. It was good in every respect. The finished assistant from the soluble portion on analysis gave the following results: —

Water.	Total Fat.	Neutral Fat.	Sulphur.
35.49 %	52.28 %	0.20 %	3.62 %
37.35	52.65	0.29	3.70

This oil gave a very poor red, lacking fullness.

The insoluble portion, when finished, gave a clear, translucent oil, darker in appearance than the commercial article. It was extremely difficult to use this, as it showed a marked tendency to form a curdy precipitate on addition of water. Analyses gave the following results: —

Water.	Total Fat.	Neutral Fat.	Sulphur.
8.02 %	87.76 %	2.08 %	0.81 %
8.63	88.59	1.78	

This gave a dull red, rather inclined to spot.

In the next experiment oil was treated with its *own weight* of sulphuric acid. Forty-four hours were consumed in introducing the acid. After all was in it was allowed to stand for twelve hours. A portion of this oil finished as in practice was analyzed, with the following results: —

Water.	Total Fat.	Neutral Fat.	Sulphur.
20.95 %	72.46 %	1.12 %	1.87 %
21.48	72.66	1.24	

It gave a dull, uneven red. Considerable difficulty was found in separating this oil into water soluble and insoluble portions, but a sep-

aration was finally obtained with the differences in the color of the oils before noted. Analyses of the soluble portion gave the following results: —

WATER.	TOTAL FAT.	NEUTRAL FAT.	SULPHUR.
28.94 %	56.72 %	0.40 %	3.55 %
31.84	57.09	0.37	3.44

It gave a dull red. The water insoluble portion was finished, and gave a very dark oil with the following composition: —

WATER.	TOTAL FAT.	NEUTRAL FAT.	SULPHUR.
9.39 %	85.67 %	1.31 %	0.86 %
9.86	86.52	1.15	

This gave a scant red, inclined to spot.

As a last experiment castor oil was treated with *twice* its weight of acid. A long time was consumed in introducing the acid. On addition of water, the temperature rose to sixty degrees centigrade, with a copious evolution of sulphurous anhydride. A fresh lot was started, and snow used as a diluent. Although the temperature sank considerably below zero degrees centigrade still sulphurous acid gas was evolved. The product was a tough, viscid mass, light brown in color, and insoluble in water. It was therefore unfit for dyeing purposes. A portion was finished, and analyzed with these results: —

WATER.	TOTAL FAT.	NEUTRAL FAT.	SULPHUR.
9.43 %	88.14 %	2.41 %	0.41 %
9.43	88.90	2.16	0.48

It will thus be seen that the effect produced by the differently soluble portions is varied by the proportion of the acid used. The best red

was produced by that oil which was treated with one half its weight of sulphuric acid. Accordingly the soluble and insoluble portions of this oil were mixed in different proportions, to see which was the most valuable. It was found that when mixed in equal parts, the red produced was quite good. Thus it seems that these bodies should be present in these proportions. All other combinations chosen gave poor reds.

As a final experiment a soluble oil was prepared. Seventeen parts of castor oil were boiled with fourteen parts, by weight, of caustic soda solution of forty degrees Twaddell. When completely saponified, enough hydrochloric acid was added to precipitate the fat acids. These were then neutralized with ammonia until an emulsion of them was readily cleared by a few drops of ammonia. This gave a good clear oil, darker in color, and possessing a different odor from the ordinary assistant. Analyses were made with the following results: —

Water.	Total Fat.
13.14 %	84.78 %
14.45	86.22

It contained no neutral fat. Reds dyed with this were good. In comparison with the red which has been designated as the best, it seems to lack lustre or "bloom," and to be considerably more blue.

One of the prominent theories in regard to the action of alizarine assistant, is the so called physical theory of Müller-Jacobs[1] and S. Jennys[2]. They maintain that the essential part of the oil is the unchanged fat, while the other portions are merely the vehicle for the neutral fat. This theory does not seem to be substantiated; for while an oil containing thirty-three per cent of neutral fat gave a very poor red, one containing less than two per cent gave good results. A soluble oil also gives good reds, which are in no way improved by the admixture of castor oil. The effect was rather to the contrary. Thus it would seem that the action of the acid produces bodies which enter into the lake, and impart superior qualities to it.

[1] Dinglers, 251, pp. 499 and 547.
[2] Bull. Soc. Mülhouse. 1868, 747.

RECEIPT FOR THE PREPARATION OF ALIZARINE ASSISTANT.

For a receipt the following is recommended: Place the oil in stone crocks surrounded by running water. Treat the oil with one half its weight of sulphuric acid of sixty-six degrees Beaumé. Add the acid in small portions, and stir well on each addition. About ten hours should be consumed in introducing the acid. Allow to stand twelve hours, and wash four times with salt and water. Neutralize carefully with soda or ammonia. It is best to use small quantities of castor oil for treatment. This should give a good clear oil, and produce good reds.

PREPARATION.	DESCRIPTION OF OIL.	Water.	Total Fat.	Neutral Fat.	Sulphur.	DESCRIPTION OF RED.
A. Castor Oil, with one quarter its weight Sulphuric Acid.	Most opaque of all, amber color, and no cloudiness.	13.29 % 14.08 12.96	83.89 % 83.89	34.22 % 33.38	0.11 %	A dull red.
B. One half its weight Sulphuric Acid. Commercial product.	A good, clear oil, amber colored.	37.45 39.02	54.51 54.38	1.71	2.02 1.92	Good reds.
C. One half its weight Sulphuric Acid. Portion soluble in water.	A clear oil, lighter colored than B or D.	35.49 37.35	52.28 52.65	0.20 0.29	3.62 3.70	A scant red; lacks lustre.
D. One half its weight Sulphuric Acid. Portion insoluble in water.	A clear oil.	8.02 8.63	87.76 88.59	2.08 1.78	0.81	Poor reds, better than C.
E. Equal weight Sulphuric Acid. Commercial product.	A clear oil, redder than B.	20.95 21.48	72.46 72.66	1.12 1.24	1.87	A full red, lacking tone.
F. Equal weight Sulphuric Acid. Portion soluble in water.	A cloudy oil, lighter colored than E.	28.94 31.84	56.72 57.09	0.40 0.37	3.55 3.44	Not so full as E but more fiery.
G. Equal weight Sulphuric Acid. Portion insoluble in water.	Similar to E.	9.39 9.86	85.67 86.52	1.31 1.15	0.86	A dull red, quite spotted.
H. Twice its weight Sulphuric Acid. "Burned" Oil.	Viscous and opaque, light brown color, peculiar odor.	9.43 9.43	88.14 88.90	2.41 2.16	0.41 0.48	
K. Soluble Oil. Castor Oil Soap.	Dark colored as C, characteristic smell.	13.14 14.45	84.78 86.22			A fair red, blue, and lacking "bloom."

Mass. Institute of Technology.

RULING GRADIENT.

BY ELIOT HOLBROOK, S.B.

HOW well I remember while yet struggling to master the contents of certain red-covered text-books, that what then seemed a grand idea slowly settled itself into the seat of my understanding. I saw how, with one grand effort, the profile of a road was fixed; I saw how, when we had ascertained what grade was practicable over some range of hills, or perhaps across some deep valley, we had fixed the grades for perhaps one hundred miles on either side. For having determined the ruling gradient, we should use it wherever it was less expensive than another.

A few years later I was called upon to see what could be done to meet the constant demand for cheaper transportation; and transportation in all its details must be studied. I saw that the operating department was taking advantage of certain peculiarities of the profile, and doing what the locating engineer never dreamed of. From observations while riding on freight trains and while at the dispatcher's desk, I saw the trouble caused by a badly broken profile; and, finally, I saw that my idea of a ruling gradient was a delusion.

I saw that in building a road the problem to be solved was how, with a given amount to expend, to make a road which could be operated for less expense than any other that could be built for that amount; and if the amount to be expended was not fixed, to determine how much should be expended to give the best returns in operating profit.

The problem is complex. If lines are already built with which you must compete, they must be studied, that you may know what they are capable of doing, at present or in future.

It will be usually throwing away money to build a line more expensive to operate than your competitor, or even as expensive, for you will only get business at profitable rates when there is more business than your competitor can do. The relation of your line to water transportation should be carefully studied. The business of the cities, towns, and country along and adjacent to your line must be studied.

Business may be much heavier on some portions of a line than on others. This has great bearing on determining the profile. The business of a line may be accumulative in its heaviest direction; that is, if it runs through a larger wheat, coal, lumber or ore region, it will pick up freight so that the amount arriving at one end may be several times as great as that leaving the other. On the other hand, the freight may be distributive in its heaviest direction, as the case of a road which brings

coal and raw material from one end of its line to a manufacturing district, especially if the products of manufacturing largely go back in the direction from which the raw material comes, as in the case with most Eastern roads.

Likewise the traffic of a road may be either accumulative or distributive in the direction of its lightest traffic. We may have on a line of road any possible combination of these cases over the whole line or a part of it, and these conditions may change with the season.

If we consider only what has been said above, it will be seen that the relative importance of grades may depend largely upon their location and direction; so much so, that on a road that has only a limited number of empty cars to be taken to one end of the road and picks up loads returning, a grade of one hundred feet to the mile at one end against the direction of empty cars, may not be as objectionable as a grade of ten feet to the mile against the direction of loaded cars at the other end.

Having made a careful estimate of the probable business of the proposed line in all its particulars for the present and future (when doing this do not base your estimates in any way on the rates that the lines which are to be your competitors now get, but rather see what your competitors are capable of doing), you are prepared now to take up the study of physical features of the country through which the line is to go.

In studying the expenses of conducting transportation of a road, we will find for a given number of cars transported in each direction, that some of the items of expenses are independent of the number of trains employed to transport this number of cars, while many items are very nearly proportionate to the number of trains, and a very few are increased by diminishing the number of trains.

Further, the experiences of numerous single track roads has shown that it is rather the number of trains that limits the capacity of the road, than the number of cars. To illustrate: a road over which trains of 60 cars can be drawn, can handle 600 cars per day with nearly as great ease as 200 can be handled on a road that can only pull 20, provided the sidings are proportionately long; at the same time, scarcely more than one third as many engines are required.

Our problem now is to see, with the means at our disposal, how to get a line over which we can get our traffic with the least possible expense; and as we have seen, this means, in general terms, with the least train mileage, or in other words, with the greatest average number of cars to the train. Every attempt should be made to locate the line so as to get the heavy grades where the tonnage is small. It will be found that it will often pay to spend large sums to avoid a short piece of heavy grade when

there are long pieces of level track on either side. You will find if you can get twenty or more miles of low grade in a place, you can double your engines on the hills.

If your line obliges you to go from a certain point in a valley to a gap in a range, it will not usually be policy to lengthen the line to keep down the grade unless it is an extreme case, and the amount of curvature is not increased too much.

The least mechanical energy is expended by moving from the base to the summit in a straight line. For every 360 degrees of curvature, you have added work equivalent to raising the same eighteen feet; you also rapidly increase the cost of maintenance.

What may be called a double ruling gradient, can often be worked advantageously; that is, a low grade used in as long pieces as possible, and then a grade where one half as many cars can be pulled. This may be found in this way. Example: We find we can build from 20 to 40 miles with no grade greater than 40 feet to the mile, but must finally climb a range with a much steeper grade; what grade can I pull half as many cars as on the 40′ grade?

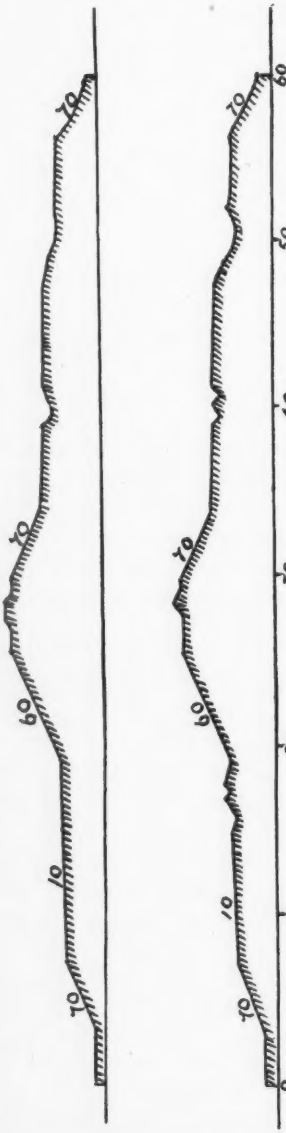
The resistance caused by friction equals the resistance of gravity on a 16′ grade. Therefore, total resistance of 40′ grade equals resistance of gravity on 56′ grade.

We will estimate weight of engine and caboose at 10 per cent of the train; therefore, with half the cars of the train we will have 10 per cent plus 45 per cent, or 55 per cent of the former weight. Therefore, the resistance may be increased in the ratio of 55 to 100, or $\frac{100}{55}$ of 56, equal 102. Deducting 16 for the resistance of friction of train, we have 88′ as the double of 40′. The example may be reversed; that is, from the grade that it is necessary to use on the hill, you may want to use one in the level district where you can double the trains used on the hills.

In all questions of grade, the number of engines required in each case should be considered. If grades can be altered to save the service of one engine, you have $8,000 to expend in grading without increasing to total cost of your road and equipment, while you save the perpetual attendent expense of the engine, and probably save in maintenance of way expenses also.

There are many roads in operation which have gone on buying engines, when the money spent for these engines expended in reducing some of the grades, would save the expense of operating and repairing those engines, and still larger expense as the business increased.

The introduction of couplings without free slack and with power brakes, will remove the objection that has been raised to larger trains in the past. The tendency at present is decidedly for larger trains, and is opposed only by those who have never tried it.



With an example of the application of ruling gradients as it has been used in the past, I will close.

The lower diagram is a representation of the profile of sixty miles of existing road, and the upper one is the same, slightly changed to facilitate traffic. The direction of lightest traffic is from 60 toward 0. A fair estimate will be that one half the cars are empty between 60 and 40, and that two thirds of the cars are empty between 40 and 0.

With the heaviest class of engines generally in use, twenty-five loaded cars can be drawn from 0 to 60, and fifty empties can be drawn in the other direction.

At present the traffic is worked in this way: An engine takes a train from 0 to 7, and returns and takes another train and takes both trains from 7 to 16, when it takes the original train again. One or two trains per day are set off at 30, and are taken away three or four cars at a time by other trains, as they can draw three or four cars more through the gaps at 40 and 50, than they can draw from 16 to 28.

With the profile as changed, the operation would be as follows: the double of the train drawn from 0 to 7, would be taken to 19 instead of 16, and would also be taken from 26 to 60. This would require some trains to double, returning between 60 and 56, and between 34 and 30. Now let us suppose that the heaviest traffic is three hundred cars per day in each direction, and that the engines make one hundred miles per day, let us see what some of the principal items in saving amount to, as at present:

12 trains each way are required between 0 and 7 equals 168 miles.

6	"	"	"	7	"	16	"	108 "
12	"	"	"	16	"	30	"	336 "
10	"	"	"	30	"	60	"	600 "
			Total,					1212 "

Profile changed.

12 trains each way would be required between 0 and 7 equals 168 miles.

6	"	"	"	7	"	19	"	144 "
12	"	"	"	19	"	26	"	168 "
6	"	"	"	26	"	60	"	408 "
Add for 3 trains doubling,				60	"	56	"	12 "
" 2	"			34	"	30	"	8 "
Saving in train mileage 304 miles.			Total,					908 "

The slight changes in the profile only reduces the mechanical energy required to move a given weight from 0 to 60, three per cent, and the less number of engines required to be moved takes two per cent from the total work of moving the traffic; so we cannot say that we save much in fuel or repairs of engines, as the fewer engines are worked harder on the light grade, but we will save the expenses of three crews, or about $50 per day, besides some saving in maintenance of way and telegraph service. At the same time, the capacity of the road is increased.

Had the road originally been built on the changed profile, the increased cost would have all been confined to about four miles of grading, and would have been less than $100,000.

To the saving of $50 per day, add the interest on the cost of three engines and the deterioration in value of the same, and we will find that saving in wages and motive power alone will reach twenty-five per cent on the investment.

In the case of this piece of road, a short piece of the ruling gradient, less than a mile long, was used at miles 17, 18, 28, and 40, and one less than two miles long at 50, with what result we have seen. This is only one case of hundreds where roads are handicapped by engineers who have made no study of transportation matters.

When changing the short steep grades, it may often be done in a manner which will meet the wants of the case, and yet cost much less, to change the whole piece. For example: the total height of the point at 38 above the level on either side is forty-two feet, and in our case the

engine is able to pull steadily twenty-five loads up this grade, and we want to pass them with fifty. This point being three miles from a station, the train can approach it at full speed when going toward 60. Now, since the engine can pull half the train up this grade, we may roughly say that the momentum can be expended on the other half, which would lift it from twenty to thirty feet; so that for half the distance we may let the grade remain, and change the upper part only to a grade over which a train can pull twice what it can on a seventy foot grade, or, $\frac{70+16}{2} - 16$ equals 27.

If we go into the details of the calculation, it will be found that if the summit is lowered eight feet, the momentum acquired in moving from 26 will enable the engines to take the trains over without trouble.

NOTES ON THE ENGINEERING LABORATORIES OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

BY GAETANO LANZA, S.B., C.E.

Taken from Minutes of Proceedings of the Institution of Civil Engineers, London. Vol. XCI. Session 1887–88. Part I.

THE Mechanical Engineering Laboratory at the Massachusetts Institute of Technology was established during the school year 1873–74, and received a considerable extension in October, 1883; the Mechanical Laboratories or workshops were established in October, 1876; and the Laboratory of Applied Mechanics was added in October, 1881.

Of these, the first mentioned was organized by Prof. Channing Whitaker. The apparatus consisted of a complete outfit for making accurate boiler and engine tests, with both saturated and superheated steam. There were (*a*) two horizontal tubular boilers, each 4 feet in diameter and 12 feet long, containing fifty 3-inch tubes; (*b*) one small vertical tubular boiler, 3 feet in diameter and 7 feet high, containing fifty 2-inch tubes; (*c*) a cast-iron superheater; (*d*) an 8-inch by 24-inch Harris-Corliss engine with a brake on the fly-wheel; (*e*) a combined surface condenser and calorimeter, with the necessary tanks and scales; (*f*) also a variety of accessory apparatus, as indicators, gauges, etc. From this laboratory there emanated an investigation into some special problems on cylinder condensation, made for Mr. George B. Dixwell.

This laboratory was further improved a year or two later by the addition of a mercury column, and considerable work was done in testing indicators, gauges, etc. It remained in substantially the same condition, being used for the instruction of the students until the summer of 1883, when the author was called upon to take charge of the department, and he at once proceeded to extend the scope of the laboratory.

The mechanical laboratories or workshops were established by Prof. J. D. Runkle, at that time President of the Institute. He conceived the idea by observing the work of the Imperial Technical School at Moscow, as exhibited at the Philadelphia Centennial Exhibition.

The Laboratory of Applied Mechanics was started with a Fairbanks testing machine of 50,000 lbs. capacity, which, besides being used for making tensile tests of iron, wire rope, etc., was also transformed in such a way as to enable full-sized beams to be tested for transverse strength and deflection, the allowable spans being any up to twenty-five feet. While this laboratory has since been much enlarged, both in space and in equipment, the work upon the transverse strength and deflection of full-sized timber beams, both under concentrated and distributed loads, and on the strength of framing joints, has all along been a feature of the work of the laboratory; and the fact has been ascertained that the actual breaking strength of such timber beams is only about one third or one half as great as would be determined by calculations based upon the constants given by such authorities as Rankine and Laslett in England, or Trautwine, Rodman, and Hatfield in America. The reason is, that the constants which they give are based upon tests made upon small pieces, and hence are not applicable to cases which occur in actual construction. The resulting constants for full-sized beams, as determined in this laboratory, have been published in both countries, and are now generally accepted as correct wherever they are known.

The other machinery in this laboratory consists of,—

(*a*) An Olsen testing machine of 50,000 lbs. capacity, for tension and compression.

(*b*) Apparatus for making tests on the transverse strength and deflections of full-sized beams.

(*c*) A machine for testing the tensile strength of mortar and cements.

(*d*) A Prony brake, and other machinery for making tests on the strength, twist, and deflection of shafts subjected to a combination of twisting and bending.

(*e*) A machine for testing the strength of ropes.

(*f*) The necessary accessory apparatus for measuring stretch, twist, deflection, etc.

The primary object of this laboratory is, of course, the instruction of the students; and it is believed that, besides the work in the recitation-room upon the strength of materials, they should be taught to do the testing themselves, to obtain accurate results, and to observe the behavior of the materials when under stress.

While a considerable amount of investigation has been carried on in this laboratory, the experiments upon the transverse strength of timber, and on the strength of shafting under a combination of twisting and bending forces, are probably the most original, though some work has been done upon the modulus of rupture of cast-iron in the form of window lintels, upon the behavior of steel under stress at different temperatures, and upon the effects of different methods of holding wire rope, etc.

This laboratory work, as well as the recitation-room work in applied mechanics, is required not only of the students of mechanical engineering, but also of those of civil engineering, of mining engineering, of architecture, of electrical engineering, and of physics. Since October, 1883, a much greater amount of space, and a much more extensive equipment, has been allotted to the Laboratory of Mechanical Engineering, making it really a laboratory of mechanical engineering, and not merely a steam laboratory. It now contains: —

(*a*) An 80-HP. Porter-Allen engine, by which power is also furnished to the new building and to the mining department.

(*b*) A 16-HP. Harris-Corliss engine, used almost exclusively for experimental purposes. This is furnished with two governors, one an automatic cut-off, and one a throttle governor, so arranged that either can be used. The automatic cut-off governor is so constructed that the speed of the engine can be varied at will.

The exhaust of each engine is connected with a surface condenser, and thence with a tank on scales; thus the water passing through the engines can be weighed.

(*c*) Three surface condensers, one of which is arranged in sections, so that the condensing water can be made to traverse the length of the condenser once, twice, or three times, at the option of the experimenter.

(*d*) Machinery for determining the tension required in a belt, to enable it to carry a given power at a given speed, with no more than a given amount of slip, whether the belt is horizontal or vertical, also so arranged as to make tests of rope transmission.

(*e*) Two friction-brakes, so constructed that a given amount of work can be put on either engine at will, and can be accurately measured; also two portable friction-brakes.

(*f*) Steam and vacuum pumps as follows: of the former, one Worthington, three Blake, one Deane, and one Knowles; of the latter, one Blake and one Deane air-pump, the Blake air-pump being connected with the condenser of the Porter-Allen engine.

(*g*) Three calorimeters.

(*h*) A transmission dynamometer.

(*i*) A 6-inch Swain turbine wheel, so arranged as to be under a head of 15 feet; experiments being made on the power developed, the efficiency, etc., under different gates; the power exerted being used up by a small brake on the shaft, and the water used being ascertained by passing it over a weir, and measuring the head by means of a hook-gauge.

(*k*) Apparatus for testing injectors.

(*l*) A Mack injector.

(*m*) A Hancock inspirator.

(*n*) A mercurial pressure column.

(*o*) A mercurial vacuum column.

(*p*) Apparatus for testing indicators under steam-pressure.

(*q*) Apparatus for determining the quantity of steam issuing from a given orifice under a given difference of pressure.

(*r*) Cotton machinery as follows: a Whitin card, an English drawing-frame, a Lowell speeder, a Lowell fly-frame, a Lowell ring-frame, a Mason mule, and a yarn-tester.

(*s*) Apparatus for calibrating weirs.

(*t*) Apparatus for testing dynamometers.

(*u*) An 8-HP. steam-engine used for setting valves, etc.

(*v*) Four horizontal tubular boilers, and all the apparatus necessary for making evaporative tests.

(*w*) A good supply of indicators, gauges, thermometers, anemometers, scales, and other accessory apparatus.

(*x*) Also a Brown 40-HP. engine, a horizontal tubular boiler, a Deane pump, and a number of looms at the shops.

The work in this laboratory is required of the mechanical and also of the electrical engineering students.

Of the teachers, those who have duties in these laboratories are the professor in charge, two assistant professors, three instructors, and three assistants.

As to the organization of such laboratories, the author believes that there are three objects to be accomplished by them; namely, (1) to give the students practice in such experimental work as a mechanical engineer is constantly liable to be called upon to perform in the practice of his profession, as evaporative tests of steam-boilers, steam-engine tests,

calorimetric tests, valve-setting, etc., teaching him to carry on his work with accuracy, and to take all proper precautions to avoid error; (2) to give the student an opportunity to carry on original investigation; (3) another important function of such laboratories, which is entirely consistent with the other two, is that of taking up and carrying out systematic investigations of engineering problems; and this can be done in a laboratory, whereas it is only with very great difficulty that it can be done in a machine-shop or a manufacturing establishment. By publishing these results from time to time, the laboratory will serve to add gradually to the common stock of knowledge.

The author recognizes very fully the incapacity of the student, as a rule, to originate and carry out research without aid from his teachers; but it is precisely because the necessary aid is given, and the necessary supervision exercised, that a considerable amount of research has been accomplished in these laboratories. This is accomplished in two ways: (1) The regular laboratory experiments are so turned by the instructor as to make them form an element in some investigations, and the students take the observations and work up the results, the necessary amount of checking being done, and the necessary supervision being exercised to insure correct results.

2. Original researches are actually carried on by the students in their graduating theses. Some of them are, of course, more able to do this kind of work than others, but all are required to undertake original research, and only such supervision is exercised as is needed.

The number of important investigations which it is possible to take up and carry out is so very large that only a few can be undertaken in any one laboratory; hence it would be exceedingly desirable to establish a constant correspondence between all the laboratories of this kind, similar to the correspondence that exists between astronomical observatories the world over. By thus reporting to each other their results, they would naturally come to so arrange their work as to play into each others' hands, and thus help along the cause of investigation.

As to tensile testing machines, probably any inaccuracies in the machines made by good makers are very much less than the unavoidable differences in quality of the different specimens of the same material.

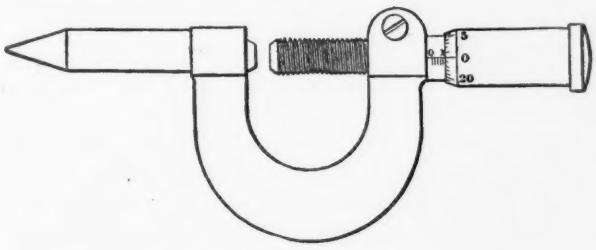
Where a large number of levers are used, as far as this applies to machines built on the principle of the platform scale, where the platform is supported on more than one lever, there is the advantage that the number of knife-edges supporting the load is greater, the pressure on each one is less, and the chances of cutting and thus changing the leverages, or of dulling the knife-edges, and thus impairing the sensi-

tiveness of the machine, are less than when one single knife-edge has to support the entire load.

The use of the platform-scale principle is becoming prevalent among American makers of testing machines. In the laboratory of the Massachusetts Institute there is one of this kind, made by Tinius Olsen, of Philadelphia, and the author has no fault to find with it.

The author is of opinion that any results on ultimate elongation, namely, on that part of the strain diagram that lies beyond the maximum load, unless very carefully interpreted, are liable to be misleading, as the ultimate elongation, and indeed the elongation in that part of the diagram which lies beyond the maximum load, will vary enormously, according to the relative position held by the point of maximum contraction of area with reference to the points between which the stretch is measured; and it is impossible to predict whether this point of maximum contraction of area will fall within the other points, entirely outside of them, or partly within and partly outside.

FIG. 1.



The stretch below the elastic limit is a matter of great importance, and it should be measured with the greatest care and accuracy. Nevertheless, if that part of the test-piece that has the smallest section is as much as 10 or 12 inches long, the section being 1 square inch or less, sufficient accuracy can be obtained for all ordinary purposes if the measuring instrument can be read to $\frac{1}{10000}$ inch.

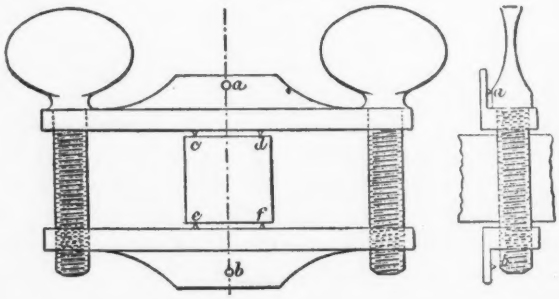
The measuring apparatus in use since 1881 consists of a Victor micrometer calliper graduated to $\frac{1}{1000}$ inch, which can easily be read to the $\frac{1}{10000}$ inch by estimation. To the end of this calliper are attached extension pieces of such lengths as may be needed in each case. The apparatus is shown by Fig. 1. As a rule shouldered specimens are not used; but whenever they are, the points between which the measurements are taken are on that part of the specimen that has the smallest

section, and never on the shoulders. Having fixed these points, clamps are fastened on, which only touch the specimen at these points. The clamps for a square or flat specimen are shown in Fig. 2. The distances apart of these clamps are measured, the average distance of two points being used with the flat, and of two or three points with the round specimen.

For compression tests the important requisites are: (*a*) rigidity in the machine, (*b*) the possibility of so adjusting the bearing surfaces as to distribute the pressure uniformly over the specimen. This latter is accomplished by means of a ball joint.

Cement testing should be, of course, one feature of a laboratory of this kind, and should include compressive and transverse tests, in both of which the all important caution to be observed, in order to insure correct results, is to have the force uniformly distributed over the cross section of the specimen.

FIG. 2.



Next, in regard to transverse and torsional tests, the fact that transverse tests require proportionately less power than tensile or compressive tests renders it feasible to erect in a laboratory sufficiently large and powerful apparatus to make the transverse and shafting tests on a practical scale. This is of special importance in transverse tests of timber.

With a testing machine of 50,000 lbs. capacity it is an easy matter to make such alterations as to enable full-sized timber or iron beams to be tested both for strength and deflection, and it has been a source of surprise to the author that this work should not (so far as he knows) have been undertaken in some other laboratory besides his own. As an example of the results that are obtained may be taken the test of a 9-inch by 14-inch yellow pine beam, 24 feet span, which had been se-

lected by a builder as one of the best of his stock. It had an actual breaking strength at the centre of 21,000 lbs., whereas the figures usually given would have made out its breaking strength to be 42,000 lbs., and some experimenters on small pieces would have called it 63,000 lbs. Similar results have been obtained with other kinds of timber.

Then, again, the strength of such framing joints as are used in buildings is constantly overestimated by builders. A slight modification of the machine has rendered it possible to make tests of these full size, and under such conditions as occur in every-day practice. While very little work of this kind has been done with rolled iron I beams, it ought to be done, and a machine of 50,000 lbs. capacity is all that is needed to break almost any of the I beams that are rolled, if advantage be taken of a span of 25 feet.

It is well known that the modulus of rupture of wrought-iron, as shown by tests of small pieces, is considerably in excess of the tensile strength; whereas those tests that have been made with I beams of practical sizes have shown the modulus of rupture to be at least as low as the tensile strength. But very little systematic work has been done on the subject.

In measuring deflections, it is important that no part of the machine should be assumed to be fixed, but that the entire deflection apparatus should be attached to the beam under test itself. The method followed is to fix one micrometer screw on each side of the beam at the middle, and then to pass a fine piano wire over two steel pins, which are fixed in the beam at the middle of its depth, and directly over the supports; fastening this wire at the two ends beyond the steel pins, and keeping a constant tension by means of a spring balance at one end. Evidently, then, the screw moves with the middle, and the wire with the ends of beams, and the differences of readings of the screw, when it is just brought to touch the wire under two different loads on the beam, gives the deflection due to the difference of the loads, an average of the measurements on the two sides being taken to make up for warping, the position of the screw when it touches the wire being determined by means of a battery and a galvanometer placed in the circuit.

The question of the effect of time on the deflection of timber subjected to moderate transverse loads is another important subject of investigation, in regard to which what little has been done has shown that the modulus of elasticity to be used in computing deflections of timber beams should be considerably reduced from those usually given, if the beam is to be designed so that its deflection shall not exceed a certain given amount when time is taken into account.

The modulus of rupture of cast-iron is an old and vexed question; and although no longer used in building, cast-iron is still employed in a great many places where its transverse strength comes into play, as in window-lintels, in pulleys, gears, and gear-teeth; and its strength, when devoted to these uses, should be investigated. Thus far only the case of window-lintels has been taken up.

In regard to shafting, the author considers that, for a pure torsion machine, the ideal form is that which Wöhler used for this purpose, the force causing the twisting being divided into two equal parts by a system of leverages, the two halves acting in opposite directions on opposite sides of the shaft, the twisting moment being thus actually applied in the form of a statical couple, and preventing any bending, of which no account is taken in the calculations. On the other hand, a study of pure torsion is a very small part of the shafting problem. By far the greater number of shafts in use are subjected to a combination of twisting and bending, the former being due to the work transmitted, and the latter to the pulls of the belts, the pressure on the crank-pin, etc. Under certain circumstances the bending may have the greatest influence, while the twisting may be predominant in others, or their influence may be equally divided.

With a view to determine the behavior of shafting under such a combination of conditions by actual experiment, suitable machinery had been put up in his laboratory. The principal points in the method of procedure were the following, viz.: —

1. The shaft under test is in motion, and transmitting an amount of power which is absorbed and accurately weighed by a Prony brake.

2. A transverse load is applied, which may be varied at the option of the experimenter, and which is weighed on a platform scale.

3. It is intended to adjust the proportion between the torsional and transverse loads, to correspond with the proportion between the power transmitted and the belt pulls sustained by a shaft in actual use.

4. Tests are made, not only of breaking strength, but also the angle of twist and the deflection, under moderate loads, are measured.

In testing a shaft, the power is obtained from another shaft, and is transmitted to this test-shaft through a double Hooke's joint, and thence to a Prony brake through a double Hooke's joint on the opposite side. The power transmitted, and hence the twisting moment, is determined by means of weights at the end of the brake-lever, and the readings of a revolution counter. The boxes in which the experimental shaft runs rest upon a casting, which, in its turn, rests upon the platform scale, and is separate and distinct from the rigid frame, which latter is firmly

fastened to the floor of the laboratory. It follows that any weight resting upon the shaft under test, or the pulley which is on this shaft, is weighed directly on the scale; the flexibility furnished by the double Hooke's joints renders it possible to determine the weight on the shaft. The transverse load is applied by screws pressing down the boxes of an upper shaft, and causing a second pulley to press against the pulley above mentioned, and thus load the shaft transversely. In making an experiment upon breaking strength, the transverse and the torsional loads are adjusted at the option of the experimenter, and then the shaft is run until fracture occurs. If the loads applied are too small to cause fracture they are increased, and the shaft is run until fracture occurs.

It has been shown by these tests that in order to deduce any conclusions of value, the time occupied in breaking must be taken into account; thus the load required to break a shaft is much smaller if a week or ten days is allowed for it to run before breaking, than if it is to be broken in a short time, as one hour.

A description will now be given of the apparatus for measuring twist under moderate loads.[1] Two disks, made of brass, are placed on the shaft near its opposite ends respectively, each disk being in two pieces, so that they may be easily put on or removed from the shaft. At the centre of each disk is a boss, a little more than $1\frac{1}{2}$ inch in internal diameter, and carrying eight set screws (of which only one is pointed) for centering the disk and fitting it to any shaft of $1\frac{1}{2}$ inch diameter or less. The outside of the boss is turned down to form a bearing; on one disk for two wrought-iron arms, and on the other for one arm. One of the arms on the first disk carries a brass brush, pointed with platinum, which presses against the circumference of the disk as it revolves, and so also the arm on the second disk carries another brush, fixed in the same manner. The second arm on the first disk carries a tangent screw, which presses against the arm with the brush. The arms are kept from revolving by suitable stops fixed in the frame, while the disks revolve under the brushes. The two brushes are insulated from the arms, but connected to each other by a wire, a battery and a telephone being placed in the circuit. The circumference of one of the disks and a portion of that of the other are of India rubber, except that at one point in each circumference a thin piece of platinum is let into the India rubber connected with the metallic portion of the disk, the circuit being completed through these pieces of platinum, the disks, and the shaft, so that if in the revolution the two brushes strike

[1] *Engineering.* Vol. XLIII. p. 26. Jan. 14, 1887.

their respective pieces of platinum at the same instant, there is a current, and consequently a ticking in the telephone; whereas, if they do not strike it at the same instant, there is no current, and hence no sound in the telephone. The manner of using the apparatus is as follows: Start up the shaft with a very small load on the brake, screw the tangent screw until a ticking occurs in the telephone, and measure (with a micrometer calliper) the distance apart of two metallic points, which are fixed in the arms for that purpose, at the same distance from the centre. Next put on the desired load on the brake, and again screw the tangent screw until ticking occurs in the telephone, and measure the distance apart of the same two points. The difference of the angles corresponding to these two chords, gives the angle of twist corresponding to the differences of the two loads on the brake.

In the work thus far described, and indeed in all the work of both laboratories, the endeavor is made to perform all the tests under such conditions as occur in every-day practice.

MECHANICAL ENGINEERING LABORATORY.

As a matter of course, tests of steam-boilers and steam-engines are subjects of prime importance in such a laboratory. Professor Lanza is of opinion that for any one boiler and any one engine, there is a certain limit to the number of variations that can be introduced, and which cannot be exceeded without at the same time bringing in such proportions and conditions as would render the results obtained inapplicable to practice, and thus render any series of investigations made by the use of these variations of but little value when considered from an engineering point of view.

Hence, in such a laboratory there should either be more than one engine, or else the range of variables should be so limited as to be consistent with the proper working of one engine. For instance, it seems hardly possible to obtain reliable results applicable to single engines by running a compound engine, either with high-pressure steam in one cylinder alone, the other being out of action, or with high-pressure steam in both cylinders; hence, unless both a single and a compound engine can be afforded in a laboratory, tests on one kind only should be adopted.

BOILER TESTS.

In regard to tests of the evaporative power of steam-boilers, it is much more satisfactory to make the tests upon a reasonably large boiler

than upon a small one; and if a large boiler is used to its best advantage, it is absolutely necessary that the steam should be employed for some purpose other than running a small experimental engine in the laboratory, as this would require so small an amount of steam as to render it very uncertain how much steam was actually evaporated, and also to cause the boiler to work very inefficiently. Hence it is better to make tests of a boiler from which steam is used in large quantity, either for heating large buildings, or for running an engine which has a considerable amount of work to do, or both. If this is not the case, the steam must be allowed to escape somewhere; and this is annoying to the neighbors, and is not a condition met with in practice. Next, in regard to the method of making the test, Professor Lanza refers to two matters that he considers of great importance, the first being that of drawing fires at the beginning and end of the tests. Professor Lanza always insists with his students that the only way to make the test (usually a ten-hour test) accurate, is by drawing the fires at the beginning and end, and he would feel that otherwise he would be encouraging careless work in a matter where the greatest caution is needed to avoid any wrong conclusions, and where so many people are ready to delude themselves and to deceive others in claiming extraordinary evaporative efficiencies.

Another condition upon which he insists, and which many are in the habit of neglecting, is that, just before the beginning of the test, the boiler shall be running under its regular conditions, the pressure being approximately that which is to be carried throughout the test, and the brickwork all hot; otherwise, starting with a cold boiler and finishing with a hot one, an error is made equal to the amount of heat used to heat the brickwork, which may be considerable.

As to the feed-water, if a pump is used it is a simple matter to weigh the water before it enters the pump, and to take its temperature by means of a thermometer in the feed-pipe, and just before it passes by the boiler check-valve. By observing this condition a heater may be used if desired, provided the heater does not leak, and that the temperature of the water is observed after it has left the heater.

If, on the other hand, an injector is used for feeding, the steam used in the injector should be added to the feed-water, and this may be done with a good degree of approximation by taking the temperature of the suction and that of the delivery after it has passed the injector, and estimating from these the steam used per pound of water fed; the temperature of the feed should, of course, be considered as that which it has just before entering the boiler. If an injector and a heater are both

used, the delivery from the injector passing through a heater before entering the boiler, it will be necessary to take three temperatures; namely, that of the suction, that of the delivery before entering the heater, and that which it has after leaving the heater. It need not be added that a boiler test, to be reliable, should be at least a ten-hour test.

PRIMING AND SUPERHEATING.

Another matter that requires attention is the amount of priming or superheating. If the boiler is a vertical one, or if its arrangement is such as to give rise to superheating, it will only be necessary to screw into the main steam-pipe, soon after it leaves the boiler, a thin metallic cup filled with either mercury or oil, and in this insert a thermometer, to register the temperature of the steam. If, on the other hand, there is priming, it becomes necessary to use some form of calorimeter; the author has never had any trouble in using a Barrus continuous calorimeter of the old form.[1] The newer form[2] also works well. In regard to the difficulties that many persons have with calorimeter work in getting superheating when they know there is none, Professor Lanza believes that a great deal of trouble is due to working with a varying pressure; for, if the pressure varies by any considerable amount, a calorimeter becomes useless. The reason for this will be evident from the fact that if the pressure decreases, then steam of a lower temperature comes in contact with a hotter pipe, and evaporation takes place, and hence less priming is shown than really exists, while the reverse is the case with an increasing pressure.

STEAM-ENGINE TESTS.

There are three principal ways of conducting steam-engine tests, as far as the determination of the amount of water actually used by the engine is concerned. The first is that which was followed by Isherwood, and by a number of others, by which the water consumption is ascertained by isolating the boiler from all uses except supplying the engine, and weighing the water fed into the boiler. In order to obtain reliable results by this method, several conditions must be observed as follows:—

(*a*) The engine must be of such size that a small error as to the height of the water-glass at the beginning and at the end shall not introduce a larger error into the results.

[1] Proceedings of the American Society of Mech. Eng., Vol. VI. p. 296.
[2] *Ib.*, Vol. VII. p. 178.

(*b*) The test must be of sufficient length, at least two or three hours, and better longer, for the same reason as stated in (*a*).

(*c*) If the steam from the boiler is used to supply the feed-pumps, the steam for this purpose must be carefully condensed and weighed, and its weight deducted from the water pumped into the boiler.

(*d*) If an injector is used, the steam must be determined as already explained and deducted.

The second method consists in determining the water consumption by condensing the exhaust steam, and either weighing it in a tank, or letting it flow over a weir and measuring the discharge. If a surface-condenser is used to condense the exhaust steam, the condensed steam is kept entirely separate from the condensing water; and hence, except in the case of very large engines, it can be weighed in a tank. In this case it is, of course, necessary to make sure that the condenser does not leak; but this can be readily determined by experiment. If a jet condenser is used, it will be necessary to determine the amount of condensing water before it meets the exhaust steam, and also the amount of the mixture, the difference being the amount of condensed steam. In this case the quantities to be determined are generally so large as to preclude the possibility of determining them by direct weighing, and to necessitate the use of a weir. Another method that might be used is the discharge through an orifice, the discharge of this orifice under different heads having been first determined by experiment. By this second method of making a steam-engine test, trustworthy results can be obtained from a test of one hour and a half or two hours, provided the power exerted is kept reasonably constant.

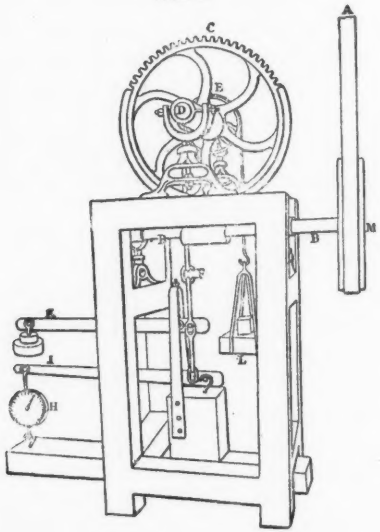
The third method is that used by Hirn, Hallauer, and others, in which the water consumption is determined at both ends. This furnishes a check, and if temperatures are taken the heat units can be checked. This method requires, of course, all the conditions of the first method, and also the precautions and measurements of the second.

As to which of these three methods should be followed in the laboratory: while it is a good plan (if the arrangements are such that it can be done on a scale that will give reliable results) to give the student some practice in either the first or the third method, nevertheless the second method, by dispensing with a consideration of the boiler, enables a much larger number of results to be obtained in the same time; and hence it seems to the author to be the most suitable for the bulk of the laboratory work of this kind, both from the point of view of instructing the students, and also in order to advance the work of investigation. In these laboratories surface condensers are used.

GENERAL REMARKS ON STEAM-ENGINE TESTS.

In regard to investigations by means of the steam-engine tests, the author is of opinion that the most prominent question of the day in this connection is upon the effect of the different conditions upon cylinder condensation; and hence upon the economy of the engine, as there has been done upon the subject a very considerable amount of qualitative work, but very little quantitative. Now, to advance much in knowledge of the subject, it is necessary that systematic experiments should be made with a number of engines of different sizes and kinds; and the larger the number, and the greater the variety of the engines experimented upon, if the work is carefully and systematically done, the more will the knowledge of the subject be advanced.

FIG. 3.



TESTING INDICATORS AND GAUGES.

All the indicators and gauges of the laboratory should be carefully tested from time to time, and tables or curves of error made out. For this reason it is very necessary that such a laboratory should contain a mercurial pressure column, a mercurial vacuum column, and apparatus for testing indicators under steam-pressure. To trust to the makers adjustments, or to the readings of so-called test gauges, is not conducive to accurate results.

FRICTION BRAKES.

There are four friction brakes in these laboratories,—two fixed and two portable. In the two fixed ones a coil of pipe is cast in the rim of the wheel, through which the cooling water circulates in a continuous stream, thus securing a good circulation, and, consequently, economy of water. In one of the portable brakes the load is applied in a manner similar to that used by Wöhler in his torsion machine already referred to, thus obtaining a real statical couple, and preventing any journal friction due to the weights in the scale-pan.

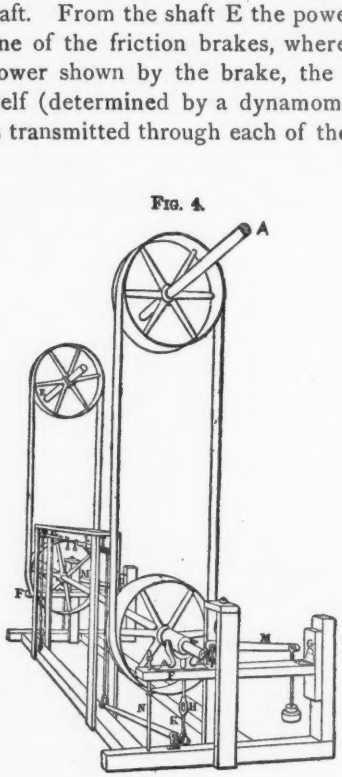
TRANSMISSION OF POWER BY BELTING.

Inasmuch as the machinery used for this purpose is novel and peculiar to this laboratory, it will be described with some degree of fullness. There are in this connection three different sets of apparatus, each accomplishing a different purpose. The object of the first is to determine experimentally the co-efficient of friction from which to work up results by the ordinary friction theory of belting; but, inasmuch as it has been pointed out by Professor Holman, of the Physical Department of this Institute, that the co-efficient of friction varies with every different speed of slip, the apparatus is arranged so as to vary the speed of slip at will, and to determine the co-efficient of friction corresponding. The apparatus is shown in Fig. 3. By means of the belt A and pulley M, the worm-shaft B is set in motion, and in its turn drives the worm gear C, and hence the shaft D and the pulley E, which is fixed to the shaft. The belt to be tested hangs over the pulley E, one end being attached by the link F to the lever I, the upward pull on this lever being registered by the dial H; at the other end of the belt is attached the scale-pan L, in which are put weights. The lever K is merely a counterweighting lever. During an experiment, the motion is imparted in such a way as to turn the pulley E in a right-handed direction, the speed of a point on its circumference being the speed of slip of the pulley under the belt, the right-hand side of the belt being the loose, and the left-hand side the tight side. The tension on the loose side T_2 is evidently the weight of the scale-pan L plus the weight in the scale-pan, while that on the tight side T_1 is read off on the dial H.

In using this machine the speed of slip at which to run it is determined by running different belts in the laboratory with revolution counters on the shafts, thus ascertaining the speeds of slip in average running, finding the power used by one of the friction brakes. The

second set of apparatus is shown in Fig. 4. The power is transmitted from the shaft A to the shaft C, and thence to the shaft E, by means of the two vertical belts; the shafts A and E being in one line, but not one and the same shaft. From the shaft E the power is transmitted by means of a belt to one of the friction brakes, where it is weighed, and by adding to the power shown by the brake, the power required to drive the shaft E itself (determined by a dynamometer), the power is determined which is transmitted through each of the vertical belts, and

FIG. 4.



by means of a revolution counter attached to the shaft C, its number of revolutions is obtained; and hence the speed of the vertical belts, and hence by division the value of $T_1 - T_2$ for each one. The boxes in which the shaft C C runs are fixed to the planks F F, and these are attached by the hinges G G to the two fixed uprights, the rod N being smaller than the hole in F through which it passes, and being merely used as a safety-stop. The planks F F are therefore free to turn up and down about the hinges G G, the levers M M being counterweighting levers. The desired tension is put upon the vertical belts after they are in position by means of the turnbuckles in the links H H, which are

attached to the levers K K, and thence to the scale-beams L L. Whenever the pulleys are of equal size, the weights on the scale-beams are the sums of the tension on the tight and loose sides, or T_1+T_2; where the pulleys are not equal in size it is only necessary to divide the weight shown on the scale-beam by the cosine of one half the angle at which the belts are inclined to each other to obtain T_1+T_2. Besides the above, a revolution counter is attached to the shaft A, one to C, and another to E, whence the slip of each belt is readily obtained as well as its speed. Knowing the power transmitted, and the speed of the belt, $T_1—T_2$ is easily found, and then from the scale-beam T_1+T_2; hence T_1 and T_2 can be determined and the width of the belt required. Hence the following questions can be answered:—

1. In order to transmit a given power at a given speed of belt, what is the least value of T_1+T_2 with which it can be transmitted without having the belt slip off?

What is the speed of slip which is obtained under these conditions, and what are the values of T_1 and T_2?

2. If a given power is to be transmitted with a given speed, and the speed of slip is not to exceed a given quantity, what is the value of T_1+T_2 required for this purpose? and what are the values of T_1 and T_2?

Having answered these questions, the question of width of belt is to be determined by so fixing it that it shall be able to bear the required value of T_1 without injury and without losing its tightness.

With respect to the third set of apparatus, the author will merely say that it is of a similar nature to the second, only that it is arranged to have the belts under test in a horizontal instead of in a vertical position; and that it is also so arranged as to enable a much larger amount of stretch to be taken up, the reason being that the first use to which it will be devoted is to test the transmission of power by manilla and cotton rope running in grooved pulleys.

TEST OF STEAM INJECTORS.

It might be well, perhaps, to mention the peculiarities in some apparatus which have been erected to test steam injectors. The suction is drawn from a large calibrated tank, and the delivery, instead of being pumped into a boiler is pumped into another tank on scales, where it is weighed, the resistance being produced by throttling, by means of a valve in the delivery-pipe. All the pressures and temperatures usual in such tests are observed, and also, in the case of the double injector, the temperature in the intermediate chamber.

THEORY OF STRUCTURES.

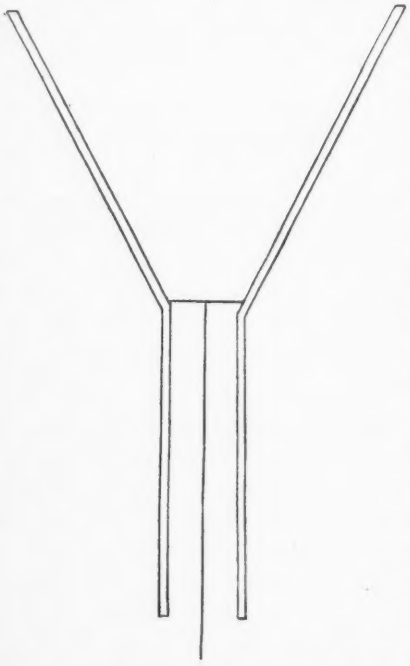
The only work of this kind as yet undertaken at the Massachusetts Institute of Technology, is the strength of such framing-joints as are used in building, and these are tested full size.

No reference has, of course, been made to any electrical apparatus, for the Electrical Engineering Laboratory belongs to another department, and is entirely distinct from any of the others.

NOTE ON A FUNNEL FOR FILTERING CARBON.

BY THOMAS M. DROWN, M.D.

THE essential feature of the funnel, as shown full size in the accompanying sketch, is the cylindrical stem; the external diameter of which should be a trifle smaller than the internal diameter of the porcelain tube into which the carbon is ultimately transferred for combustion. This stem, in the funnels used in the analytical laboratory of the Institute, has a diameter of half an inch, the porcelain tubes being five-eighths of an inch diameter internally.



To support the asbestos which retains the carbon, a flat coil of rather heavy platinum wire is used, one end of which extends from the centre of the coil to a little below the end of the stem, as shown in section in the drawing.

The asbestos, which should be well broken up, but still fibrous, is, while suspended in water, poured on to the coil when the funnel is connected with the suction-pump. It is desirable to have the funnel at least one-fourth full of asbestos. If a suction-pump is not available, a loose mass of asbestos fibre may be used, which fills the funnel about one-half or two-thirds full.

When the carbon is all on the filter and completely washed, the particles adhering to the sides of the funnel are removed by rubbing with a little moist asbestos held in forceps, and this asbestos is put on top of the carbon.

The coil of wire is now taken out of the funnel by pulling on the vertical wire in the stem, and the funnel is set aside to dry.

When ready for combustion, the stem of the funnel is inserted into one end of a porcelain tube, which contains near its other end a layer of copper oxide, retained in place by plugs of asbestos. The transference of the asbestos and carbon to the tube is very simply and completely effected by means of a glass rod. Any particles of carbon adhering to the glass are easily removed by gentle friction with asbestos. The mass of asbestos and carbon are thrust well into the middle of the tube, and the sides of the tube are freed from any particles of carbon by pushing down several light plugs of asbestos.

The advantages of this form of funnel are, first, that the cylindrical stem permits the asbestos to be immediately transferred to the tube without loss; and, second, that the wide upper portion of the funnel allows the liquid containing the carbon to be poured rapidly and freely.

Platinum tubes and boats are often used for filtering off carbon, and the great advantage in their use consists in the fact that they can be directly inserted into the porcelain tube without removal of their contents. But this advantage is accompanied by the drawback that they present but little surface for filtering, and the liquid containing the carbon must, consequently, be poured on to the asbestos very slowly, and with great caution. Where a large number of funnels are required, the expense of the platinum is also worth considering.

A copper-wire coil may be used in cases where it would not be dissolved. In filtering the acid solution of cupric chloride in the determination of total carbon in iron, I have used a moderately heavy copper wire, which, although somewhat attacked, retains sufficient strength to support the asbestos to the end of the operation.

A variation in the usual method of carbon determinations in iron and steel has been successfully tried with this funnel. The iron borings have been placed directly on the asbestos filter, and the solution of the cupric-ammonium chloride has been passed over it by means of a siphon, delivering about a drop a second.

From 100 c.c. to 150 c.c. of a nearly saturated solution of the double chloride is sufficient to dissolve all the iron, so that the residue on the filter, which contains some metallic copper, may be washed with dilute hydrochloric acid. It is washed finally with water, dried, transferred to

the combustion tube, and burned in oxygen without regard to the presence of any metallic copper which may be present.

The direct decomposition of iron by the double chloride in a glass tube in which the combustion is subsequently made, would seem to be a still more perfect method of determination of carbon, since it involves no transfer at all. But the advantage in the use of a porcelain tube for the combustion is so great, on account of its being unaffected by the sudden application of heat, and by the highest temperature of the combustion furnace, that it is worth while to take a little more time to transfer the carbon — time which is fully compensated for in the greater ease and security in conducting the combustion.

Massachusetts Institute of Technology, April, 1888.

HEATING AND VENTILATION.

[*NOTES.*]

BY S. H. WOODBRIDGE, A.M.

PROFIT AND LOSS IN SCHOOLHOUSE VENTILATION.

THE modern sanitarian takes the murderous threat, "Your money or your life," out of the highwayman's mouth, and makes it his philanthropic appeal to individuals and communities to provide for their lives. Under his persistent teaching they slowly turn their thought and their means to life's betterment along some of the more clearly recognized and demonstrated lines of sanitation, leaving others untried and unconsidered, because undervalued, since the evil results of neglect are less immediate and startling, and not so surely traced. The city which spends millions in water-works for pure water supply and in sewerage for foul water removal, is still found tightening its purse-strings when a few thousands are asked to provide for pure-air supply to, and foul-air discharge from, its schoolrooms. And yet the purity of air, from the continuous breathing of which there is no escape, may be essential to health as the purity of water which one drinks in relatively small quantities and at long intervals. Classified according to the air allowance, as determined by the air space in houses to the individual occupants, the last year's official report for the city of Dundee, Scotland, shows the effect on death rate and longevity as follows:—

Proportionate air volumes,	1	2	3	4
Proportionate death rates,	21.4	18.8	17.2	12.3
Average ages of those dying between five and twenty years,	7.	8.3	12.2	11.7

Such a method of argument, however enforced by evidence new or old, and however humane and cogent in its reasoning, passes for little with such as are insensible to appeals to any but lower motives. To a money-making, money-loving people, no plea can be so effective as that of monetary profit and loss,— of dollar *versus* dollar demonstration. For the convincing of such as listen and yield to no other argument, and for the information of those who would furnish themselves with every effective argument, the study of the dollars and cents side of a sanitary question may therefore be profitable.

What then is the money gain as compared with the output in securing good ventilation in school-buildings? The items on the profit side may be briefly summed up as follows: Shorter time of schooling in acquiring a given amount of knowledge, and earlier entrance upon, and more vigor in, subsequent remunerative work; reduced number of days lost in sickness, and less money paid in salaries to substitute teachers.

The full value of these items is not likely to appear at their bare suggestion. The first involves the rapidity of acquisition, dependent on the alertness of the scholars both individually and collectively, and the clear-headed energy of the teacher,— the regularity of attendance on the part of both scholar and teacher,— the absence of breaks in the school-work due to actual or threatened epidemics. Bad air works a double evil in depressing the teacher and dulling the scholar; it reduces vitality, and exposes both scholar and teacher to greater liability to sickness and absence,—the absence of the scholar resulting in loss through interruption of school-work, and that of the teacher involving all the disturbing results of substituting; it promotes the spread of contagious disease, and not infrequently makes closing as a prevention necessary. Schools which have suffered such almost yearly loss of weeks have, after the introduction of good ventilation, been for years free from such interruption. This much may, therefore, be included under the one item of time saved.

The actual expenditure of money is reduced as well, and that in two directions. The lowered vitality induced by bad ventilation exposes the sufferer to greater liability to disease, and to its greater severity when it comes, and therefore to a proportionately greater expense for medical treatment and attendance; and on the other hand it increases the cost of school-work, because of the extended time required to accomplish a given result, and because of the larger amount of substitution involved, when paid for from the public fund. The aggregate of these two classes of losses to be charged to the profit side, if saved by good ventilation, is probably much larger than is commonly supposed, but the

data for exact statements are not easily attainable. The record of the Pension Bureau, however, furnishes some suggestive figures. This department, heretofore scattered about in separate small and poorly ventilated buildings, has recently become established in the new, spacious, and well-ventilated building erected for its use. Meanwhile the working force has been greatly enlarged with the growth of the Bureau's work. Under the bettered sanitary conditions, of which improved ventilation, with its intimate and dependent allies, is doubtless of well-nigh exclusive importance, the time lost by sickness for one year was 10.114 days, against 18.736 under previous conditions and with a smaller total force. This reduction of nearly fifty per cent represents a gain by no means measured by days of actual sickness averted, but by a corresponding vitality of the whole working force, and money unspent in payment of doctors' and druggists' bills.

Turning now to the other side of the account, the items of loss may be summed up under two heads; first, the cost of the means for heating and ventilating above that for heating only, and second, the cost of heating the air required for ventilation. The first of these being for permanent installment may be charged on interest account. The second being a yearly account must be charged in full to those benefited by it.

The means required are, in general cases, simple. When space can be spared for generous-sized flues, machinery in the shape of fan and engine are superfluous and skilled attendance unnecessary, except in climates where the temperature is for a considerable time during the period of the building's use too cool for open windows and yet so warm as to require but little artificial heat, or in cases of unfavorable exposure of building. Twenty square inches area per capita of cross section of most contracted part of a well-planned flue system of thirty-six feet height, will secure to each pupil 1,500 cubic feet of air per hour when the outside and inside temperatures are respectively 60° and 70° F.

The necessary increased cost of construction is, first, in providing large flues and suitable dampers for controlling their air-moving capacity; and second, in the larger heating surface which may in some cases be demanded for warming to the point of comfort the greater air volume to be moved by the enlarged flues. For a large school-building of from 12 to 14 rooms, the total necessary increased construction cost would not exceed $2,000, on which the interest would be, say, $100, which divided among 600 scholars would equal an outlay of 17 cents per year on each. Assuming a required renewal of the extra heating surface once in twenty years, the additional yearly cost would be $50, or 8.5 cents per year per scholar.

The difference between the cost of simple heating and heating with free ventilation is not so easy of exact statement, but may be closely approximated. Taking as an example a brick-walled school-building 96 feet by 92 feet by 37 feet, having a mansard roof and 1,200 square feet of single-glazed window surface, estimate makes the coal required for heating alone for thirty weeks, and including that lost in banking fires, 83 tons, at a thermal efficiency of 8,000 units per pound of coal. Through faulty firing and wasteful methods of heating this amount may be exceeded by 15 or 20 tons. An air supply of 1,500 cubic feet per hour per capita for six hours a day and five days a week would, for the same time, require 32 tons, and this alone could be charged to ventilation. At $5.00 per ton, the year's cost per scholar would therefore be 27 cents, or a total of 52.5 cents a year, or a little under 2 cents per week for the thirty weeks of required artificial ventilation.

Such estimate takes no account of the waste attending the usual methods of heating without, or with only meagre ventilation, by which the ceiling air is sometimes 20° overheated to keep the floor at comfortable temperature, or the top floor overheated for the sake of warmth in the lower stories. The effect of this common condition of things upon coal combustion is more than equivalent to the economical heating of the building in a climate with a mean lower temperature of 10°, since loss by conduction through walls is proportional to the mean temperature difference between inside and outside air, and the air lost by leakage is increased in quantity and temperature,— for it is the hottest that escapes; and the more rapid the outward leakage at the top the higher the rate of inward leakage at bottom, necessitating a further heating to maintain a comfortable temperature at the floor of a room or the basement of a building. The loss by conduction and leakage is least when a uniformity of temperature is maintained throughout a building or room, and the more free and efficient the ventilation, the more sure the attainment of that result.

An illustration of this fact is furnished by the records of the heating and ventilation of the two principal buildings of the Massachusetts Institute of Technology. The Rogers Building is heated and ventilated in only a few of its most crowded rooms. The new building, of approximately the same size but with much larger window surface and thinner walls and more open interior, is ventilated to an extent equivalent to the complete change of the air of its rooms every 12 to 13 minutes, or assuming 400 occupants, with an average of over 8,000 cubic feet per hour for each occupant, and the ventilation is maintained through an average of nine hours for six days of each week of the school year.

The most perfect record thus far kept shows that for heating and ventilating the new building, 55 per cent more fuel has been required than for heating the Rogers Building, the latter having the further advantage of waste heat from the boilers and heated chimneys, and the regular heating of one of its large rooms, and, in some weathers, the heating the entire building from the new building's boilers.

Such evidence would make it appear that the difference of 32 tons estimated as the cost in fuel of ventilation, above simple heating, is too much, rather than too little, to be charged to that account. Taking, however, an estimate of two cents per week as the maximum actual cost per pupil, it is safe to declare that a very small payment for the actual monetary gain secured.

By way of illustration the Pension Office data are again suggestive. Let the total 700 tons of coal burned during the year covering the data quoted (at $4.00 per ton), represent the cost of improved ventilation, and let 8,622 days, at an average of $2.00 per day, saved from illness, represent one item of the resulting profit. The Government account of profit and loss would then stand,— profit, $17,244, and loss, $2,800; no account being made of the improved working ability of the whole force, nor of the private account of the unincurred expense incident to 8,622 days of sickness.

An estimate of the immediate dollar and cent profit due to averted illness may be based on the record of a large grammar school covering absences because of sickness, and on the assumption of a gain by generous ventilation, in the general health of the school proportionate to that realized in the Pension Office. Considering the value of a day saved from sickness worth no more than the cost to the city of one day's schooling, and assuming medical attendance on one in twenty-five cases of sickness, and the cost of substitution at one dollar a session (the absence of teachers through sickness being given the same ratio as that found for the scholars), the profit side is then found to exceed the total loss by more than 20 per cent.

All the suffering involved in five and one-half years of sickness, all the gain in the character and quantity of work done both in and out of the schoolroom, and the increased vigor of health maintained throughout school years and after life, though of incomparably greater value, count for nothing in such an estimate. Were five and one-half years of sickness directly caused by some public mal-administration other than the keeping of fresh air out of schoolrooms, the yearly draft on its treasury for damages might easily be largely in excess of the total cost of the construction and use of a good ventilating system.

VENTILATION OF THE MACHINE-ROOMS OF PAPER MILLS.

The machine-room contains the machinery required for converting paper pulp to paper. From a single machine making six tons of paper per day, there may be nine tons of water evaporated in the same time. The air rising from the steam-heated driers is saturated at a temperature of from 100° to 110°, and if allowed to diffuse through the room and cool, fog in the air and heavy condensation on chilling surfaces result, the latter injuring the woodwork of the mill, and if condensation is sufficiently rapid directly over the machine, damaging the paper in process of fabrication by the dripping of water upon it from the ceiling.

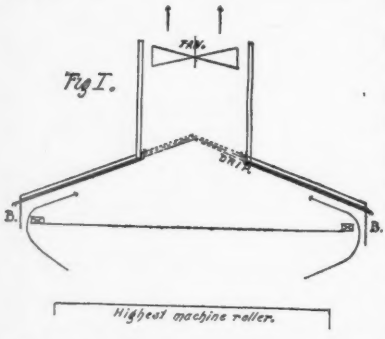
The heated air, if allowed to escape into the room, raises its temperature to a point which, with the excessive humidity, depresses and enervates the working force, not only in the machine-room but in others which may be above it, or into which, for the sake of relief, it may be ventilated.

The ordinary method of ventilating such a room is by opening the ceiling directly over those parts of the machine yielding the most vapor, and carrying upcast ventilating shafts through the roof into open air. If the shafts are large and tall, their position well chosen, and the supply to the room equal to the discharge capacity of the shafts, and especially if the room is low studded, the relief may be very considerable, but in practice it is seldom enough to prevent condensation on cooling surfaces, nor are the results economically obtained. Such a method of ventilation allows much of the heated and humid air rising from the machine to diffuse through the room before being discharged, making a larger air movement necessary for the maintenance of any desired condition of temperature and dryness than would be required were the hot and wet air rising from the machine completely and instantly removed. To attempt to ventilate the room through an aperture placed in the roof or wall, whether the motive power is effected by a shaft or a fan, is to make the whole machine-room a discharge conduit having large and exposed cooling surfaces.

The most perfect ventilation of such a room is secured when the air discharged from it is identical with that which rises from the machines,— no less, no greater, and no other,— and when that discharge is so direct and immediate as to preclude diffusion — the most efficient method of effecting such removal is by placing over the machine a hood, covering that part of it from which the objectionable air rises. The hood should overhang the machine a foot or more on all sides, and should be raised above it only to a sufficient height to afford easy working room beneath. Such a hood may have connection with a single shaft, preferably located

over that part of the machine from which the greatest quantity of steam escapes, or the outlet may be at several points along its length. In either case it is advantageous to place a diaphragm in the hood, to equalize along its entire perimeter the air current flowing into it, and to concentrate it there, so making the current strongest along the line which would otherwise be the natural line of escape of the heated and damp air. (Fig. 1.)

To prevent the possibility of the dripping of water upon the machine, due to the condensation within the hood, the latter should be made with sloping roof, which should extend beyond the machine. The diaphragm should be made of cloth stretched upon a light frame, so supported within the hood as to be easily removed for cleansing and renewal as required. The bafflers, *B B*, may also be made of cloth of sufficient stiffness or weight to keep them in the vertical position against the inward pressure caused by the strong current through the slot between them and the edge of the diaphragm.



The air to be moved may best be computed on the basis of the maximum amount of water evaporated per hour. If that rate is nine tons in a day of twenty-two hours, or 818 lbs. per hour, and the temperature of the escaping air is 110° F., the number of cubic feet of air per hour required to move the water is 260,000. Making allowance for a somewhat lower temperature than 110°, and for the excess of heated air rising from the machine, the maximum limit of air to be moved through the hood per hour may be put at 400,000 cubic feet.

If the minimum velocity of air-flow through the hood discharge-shaft is fixed at 10 feet per second, the shaft's sectional area must be about twelve square feet, and the cross section of the hood included between the roof and the diaphragm should be at least 10 square feet if the shaft is located at one end of the hood, or 7 square feet if the position of the shaft is central.

The open free space between the diaphragm and the hood should nowhere be less than 2 inches wide, and not less than 3 at that part of the hood under which the greatest part of the steam is developed. If the ventilating shaft is vertical and unprotected by insulation, and exposed for any considerable part of its length to cold air, condensation

may take place and water trickle down the walls of the flue. In such case provision must be made for catching and draining off the condensed water, to prevent its dripping through the diaphragm upon the paper.

The advisability of using a fan within the discharge shaft must depend on several conditions, principal among which are the freedom with which air is admitted to the machine-room, the height and unobstructed character of the shaft, and the extent to which it is desired to rely upon artificial ventilation in mild and warm weather. With an outside temperature of 50°, a free, vertical shaft, 3.5 feet square and 40 feet high, having an abundant air supply at bottom and an internal temperature of 100°, a velocity of flow of 10 feet per second may be obtained, allowing 50 per cent loss through resistance of friction and other causes. In general, however, the use of a fan adjusted for running at various desired rates of speed must prove more satisfactory, since the rate of air movement is then under more perfect control, and the use of the system of artificial ventilation may be carried further into mild weather; and in exceptional cases, when the room is sheltered and the air supply can be inexpensively cooled, the forced ventilation may be carried through the summer. The power required to run a fan for such work increases with the decrease in temperature difference between the flue and the outside air, but it can at no time be more than one half horse-power, except by some faulty construction.

The best action of the hood is in an important degree dependent on the quietness of the air of the room, a current of two or three feet per second between the hood and the machine being sufficient to carry a considerable part of the hot and vapor-laden air out from under the hood. Hence the currents caused by the entrance of some 7,000 cubic feet of air per minute into the room should be so distributed and directed as to cause scattered and vertical currents rather than concentrated and horizontal ones, and the areas of inflow should be so large as to reduce the rate of flow to at least five feet per second.

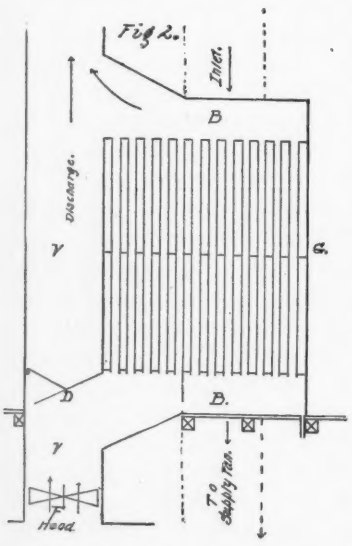
The heating of so large an air supply is the chief item in the cost of such ventilation. To heat the air through 60° would in zero weather require about 60 lbs. of coal per hour, or more than one half ton per day, and the steam-heating surface demanded would be at least 500 square feet, costing some $500, if boxing and suitable air connections are included. The average daily coal consumption through a year of seven winter months may be put at 700 lbs., making a yearly aggregate of 38 tons, costing, according to the variety used and the remoteness of mill from supply, from $100 to $250. The total yearly cost of air heating by this method, including interest on construction cost,

repairs, coal burned, and interest on coal payments, may be put at from $150 to $300, according to circumstances.

Such an outlay would, however, doubtless find a generous return in the preservation and improved condition of the mill, and the health and efficiency of its working force.

It may frequently be possible to draw the air supply through the rooms adjoining the machine-room, so effecting both their ventilation and the heating of the air in transit. The additional heat yielded by radiation from the machine driers and piping may then be sufficient to maintain the desired temperature, making large auxiliary heating surface unnecessary. Adequate means must be provided for the heating of the machine-room without ventilation when the machine is not running.

The cost of ventilation may, however, be greatly reduced by the use of suitable means for effecting a transfer of heat from the discharged to the supply air. The heat contained in the 400,000 cubic feet of discharged air and the 830 lbs. of water vapor contained in it is greatly in excess of that required for heating the fresh-air supply, even in the coldest weather. Cooling the escaping air through only 30°, the yielded heat would equal 218,000 units, and a corresponding vapor condensation would yield 400,000 more, making a total of some 600,000 against a maximum of 500,000 needed for zero weather.

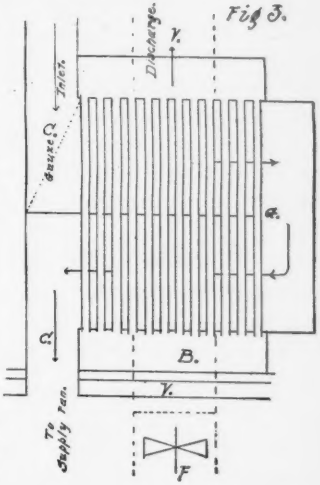


To effect the transfer the discharged air may be made to pass through a battery of galvanized iron pipes, over which the supply air is made to pass by the aid of an auxiliary fan. A possible and convenient form for such an arrangement is shown in Fig. 2. The ventilating shaft *V*, through which the discharge air escapes under the unaided action of its own levity, or preferably by the aid of a fan, *F*, has a cross section of 3 feet 6 inches by 3 feet 6 inches. By means of a damper, *D*, the air movement may be deflected from a straight course through the flue, and passed wholly, or in part, through the transfering arrange-

ment, according to the quantity of heat to be transferred to the incoming air. The boxes, *B B*, are 8 feet by 8 feet by 2 feet, and they are connected by 144 pipes of 4 inches diameter and 12 feet length, 12 of which are shown. A diaphragm, *G*, separates the free space between the boxes into two equal parts, the supply air being thus made to pass twice and in reverse directions between the pipes.

Fig. 3 gives a vertical section of the arrangement from another side, C *G* C, being conduit chambers extending across two sides of the battery of pipes, and designed to facilitate the equal diffusion of air over and movement between the pipes, which should be spaced 8 inches between centres, and in staggered order. For greater convenience in handling, the pipes may be made in two parts, one telescoping into the other, and soldered as they are placed. The lower length of each pipe should be made to extend a half-inch or so into the lower box, to prevent the wetting and rotting of the wood, and the pipe should be supported by a flange, as shown in Fig. 4. A similar flange may be placed at the top of each upper length of pipe, to aid in making a tighter joint. The bottom of the lower box should be metal lined, and arranged for the drainage of from 35 to 60 gallons of condensation an hour.

Fig 3.



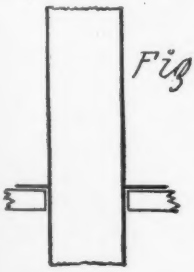


Fig 4.

The cost of such a heat transfer, with fan and air connections, would be no more than the steam-heating plant otherwise required, and the expense of using it would be that of running a one-horse power fan, costing in coal perhaps five pounds per hour if the exhaust steam is thrown out-board, and less than one half pound if the waste steam is used for any mill purpose. The gain would therefore be practically the entire cost of the coal otherwise required for heating, and the principal item of loss would be in the space occupied by the system, 8 feet by 12 feet on the floor, and 16 feet high. These dimensions may, however, be reduced without effecting a corresponding reduction in the efficiency of the transfering apparatus.

The economic value of such a method of transfer increases with the temperature difference between the outdoor and the discharged air, with the humidity of the discharged air, with its volume, and with the increased cost of fuel. Its application to the ventilation of ordinary buildings cannot have the economic value which may be realized when the discharged air is of excessive humidity. When the New Building of the Massachusetts Institute of Technology was in process of construction, the writer suggested the adoption of a plan for economizing fuel by the the transfer method. The proposed plan would, according to estimates furnished, have required an outlay, in modification of building and in special construction, of some $12,000 or $15,000. The saving in coal would, by estimates, be at least from 150 to 200 tons a year. The interest on $15,000 at 5 per cent equaling the cost of 150 tons of coal at $5 per ton, the gain under such conditions would be nothing. Yet in buildings of such character and use as are maintained by individual or governmental endowment, the adoption of such a plan might be in the line of economy, since the needed funds for its installation as part of the building's equipment, could be much more easily obtained by solicitation than its equivalent annual gift for the purchase of coal.

The above study was suggested by the application of a paper manufacturer for some method of insuring the dryness of an exposed roof built without the usual air space, and described in the following letter:—

BOSTON, April 25, 1888.

MR. S. H. WOODBRIDGE:

Dear Sir,— In connection with your description of the system of ventilation in the machine-room of a paper mill, it may be judicious to state that until a very recent period, paper-makers have assumed it to be necessary to construct the roof of the machine-room, in which the water is evaporated from the paper while in the final process of manufacture, with a large air space in it, under the supposition that such an air space is necessary to prevent the condensation of the moisture from the paper upon the under side of the roof. Hence the common method has been to put over the machine-room a pitched roof, ceiled on the under side of the rafters, or else ceiled horizontally from wall to wall at the level of the top of the walls, in the latter case making a triangular cock-loft, to which the underwriters take very serious objection. It is in these concealed spaces that fires spread with the greatest facility, while they are fully protected from the water thrown either inside or outside. Hence the effort of the underwriters has been to induce the paper-makers to

place over their machine-rooms a solid deck of wood, sufficiently thick to prevent the passage of the cold from without, and thereby to do away with the danger of the condensation of moisture on the inside, such heated vapor being subject to condense and drop from a cold surface.

The roof of the machine-room, to which your system of ventilation has been applied, is constructed in this way without any hollow space of any sort, and it has proved to be an entire success.

The effort of the Mutual underwriters is now to procure the removal of all dangerous roofs of the old kind, and the substitution of the thick plank roof corresponding to the one described. The roof is substantially of plank, three inches thick, covered with one inch mortar on the outside, then one inch sheathing, and finally covered with any kind of roofing suitable for a flat roof. It has been proved in this, as in many other cases, that solid wood is the best non-conductor of heat,— much better than confined air spaces.

At the instance of the Mutual underwriters a very large portion of the old-fashioned factory roofs, as well as of the pitched or barn roofs, so-called, and nearly all the French roofs, have been removed from textile factories and other works, all being bad forms either for use or safety.

The prejudice of paper makers has been very great in favor of a form of construction of roofs which is both unsuitable and unsafe, but at length they have become convinced that the solid deck or flat roof is the only one fit to be placed even over a paper mill. Many dangers are now being removed, and it is not probable that unsafe and unsuitable roofs will hereafter be placed even over the machine-rooms in any new undertakings.

The building which you have ventilated is constructed according to the rules which the Mutual underwriters have long advised their members to adopt. It remains for the architects who have charge of the construction of other buildings than those insured by the Mutual Companies, including dwelling-houses, to find how to construct a safe roof consistent with their æsthetic requirements, in place of what have been rightly named the "crazy roofs," under which the greater part of our modern buildings have been constructed. Ovens in summer, refrigerators in winter, and fire-traps all the time, may be the terms most suitable to be applied to the greater part of the roofs heretofore or now being constructed, outside the supervision of the Mutual underwriters.

Yours very truly,

EDWARD ATKINSON,

President.

The following is appended for the benefit of those who, distrustful of theory, are to be convinced only by the evidence of experience: —

BOSTON, May 4, 1888.

MR. S. H. WOODBRIDGE:

Dear Sir,— Referring to your inquiry as to the advantage of a thorough ventilation of machine-rooms in paper mills, I would say that it is a subject which appears to be but little understood by paper manufacturers; consequently a well-ventilated building for this purpose is rarely met with.

Poor ventilation seriously impairs the life of all wood-work, causes considerable imperfect paper; directly by water dripping from the ceiling, and indirectly by the unfavorable effect on the workmen.

Since we have adopted the method of ventilation described in your paper (without the proposed method of heating), our work-people in the machine-rooms tell me that they feel much fresher at the end of their day's work than they did before it was introduced, and as a result, the character of their work has improved.

We started our new system in October last, and up to the present time I can honestly state that we have not, under the most unfavorable atmospheric conditions, had a particle of moisture condense either on ceiling or walls

A flat roof I consider an efficient aid to good ventilation, when properly built. It relieves the machine-room of useless space which has to be heated; and presenting a smaller area than a pitch roof, there is, of course, a smaller radiating surface.

I prefer a ventilating-fan to a natural draught, as by this method one has complete control of the ventilation; and where the fresh air entering the machine-room is supplied freely, all the moisture which is thrown off from a machine in making six to eight tons of paper per day can be properly removed by a four-foot Blackman fan, driven at about one hundred revolutions per minute.

If paper manufacturers will adopt flat roofs on their machine-rooms, constructed after the specifications of the factory mutual insurance companies, and a system of ventilation such as I have referred to, they will at once see their advantage in it, and condemn their past conservatism in these particulars as stupidity.

Very truly yours,

GEO. W. WHEELWRIGHT.

A DEVICE FOR INCREASING THE EFFICIENCY OF LARGE SHAFTS EXPOSED TO WIND ACTION.

The light-shafts of buildings are often used for purposes of ventilation. If such shafts are glass covered, one or more pipe ventilators are usually placed at or near the ridge or in the peak of the skylight covering the shaft into which numerous windows may open, or doors, if the skylight is over a stair-well. The area of outlet through the ventilator is usually so contracted as to be but a small fractional part of the window or door area into the shaft, and the practical working effect of the shaft is in the conveyance of air from the lower part of the building to be effectually distributed through the upper stories, simply for the reason that, cut off from escape through the ventilator, it seeks egress through channels offering less resistance to its movement.

For the proper action of such a shaft the relation between the maximum areas of openings into and discharge from it must be fixed, the discharge area being such as to move the whole volume of air, for which outlet through the shaft is sought, at a velocity no greater than that of the slowest rate of flow into the shaft,—or that due to the available head for air movement from the uppermost story connected with the shaft.

This rule in most cases demands a practically free opening of the shaft at its upper terminal into outer air. The question then arises how such opening shall be given, and at the same time proper protection from weather and adverse wind action be secured, together with the lighting of the shaft, and such arrangement as to make wind action increase rather than diminish the ventilating efficiency of the shaft. If for this purpose the skylight is raised above the roof, and the extended sides of the shaft left open, the area may be secured without the required protection. If fixed louvre blinds are placed in the openings, or if they are covered with fine wire cloth, rain and snow may be partially excluded but not the wind. The entrance of wind must interfere with ventilating action, since the blowing of wind into an inclosure whose walls upon all sides are of the same general character in openness and exposure, produces a pressure within it which tends to force air outward in all directions but to windward, and so to interfere with, if not reverse, the upward flow through the shaft. Hence one cause for the use of various automatic devices for closing the windward and opening the leeward sides at the top of ventilating shafts, such as capping them with revolving cowls or bafflers held by wind action to the most effective position, or housing the top of the shaft with blinds, so balanced as to be always open except when closed to windward by wind force.

But cowls and bafflers are more or less tardy in action, sometimes failing in light wind to respond to its movement, and thus causing the reverse of the desired effect. They are furthermore objectionable because of the squeaking and noise attending their motion. The clattering and rattling of automatic blinds have in some cases made them such nuisances as to result in their being removed or nailed fast.

Some eight years ago the writer proposed as an above roof terminal for the main shaft for the ventilation of Huntington Hall, an arrangement adapted to light or stair-well shafts used for purposes of general ventilation, and shown in Fig. 5. The shaft walls, *S*, carried above the roof high enough to be clear of snow, are surmounted by an open frame, supporting the skylight and shaft roof. The total clearance between the top of the shaft and its roof is made equal to twice the sum of the fixed areas for the discharge of air from the building into the shaft. Frames, *F F*, covered with wire netting of coarse mesh, are placed as shown, and upon the outside of them are wire rods supporting strips of rubber gossamer six inches wide, and extending from end to end of each frame. In quiet air these flaps hang vertically. An upward air movement through the shaft moves them more or less outward, according to its force, affording free exit. An outside wind instantly closes the side to windward, and the increased pressure difference on the leeward sides results in throwing the flaps still further outward, and in proportionately accelerating the rate of outflow. The top of the shaft is covered with glass to the point *p*, and finished out in metal. The outside wire cloth is of fine wire and close mesh, not coarser than $\frac{1}{10}$ inch, and for durability is covered with a highly fluid paint. The frames on which the outer and inner wire nettings are stretched are made easily removable, for the renewal of the netting and flaps as required, both of which should be inspected every few months, in order that clogging dust, or damaged flaps may not interfere with the shaft's proper action.

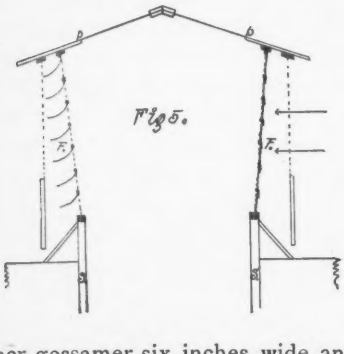


Fig 5.

If it is desired to use the shaft for inflow rather than outflow, the gossamer flaps may be placed on the inside of the wire cloth, the frame holding which had then better be given an inclination in the opposite direction from that indicated in the figure.

PRIMARY HINTS FOR THE INSPECTION OF BUILDING VENTILATION.

The fact of a sensible odor or of closeness within a building, perceivable on entering it from outside air by one having a fairly acute sense of smell, may be regarded as evidence warranting further examination.

The odor may be found to be both unavoidable in origin and harmless in character; the former when peculiar to, and inseparable from, the employment of those occupying the building; the latter when the odor is neither of such intensity nor morbific character as to be prejudicial to health.

The odor may be chiefly or solely due, however, to the presence of the occupants and the absence of a sufficient air supply. In the absence of other carbonic acid gas than that produced by respiration, the cause of an odor, as between those which are and those which are not due to inadequate air supply, may be most surely discovered by a chemical determination of the amount of that gas present in the air. By the amount by which the carbonic acid gas exceeds the normal, the evidence of imperfect ventilation as the cause of an odor increases, and by the amount by which that gas approaches the normal the evidence indicative of some other cause increases. The normal of carbonic acid gas in outside air may be put at $\frac{4}{10000}$, and $\frac{6}{10000}$ found within a building indicates an air movement through it which may be regarded as adequate for perfect artificial ventilation; $\frac{8}{10000}$ as fair for rooms occupied through long sessions, and good for those occupied through short sessions, as churches, theatres, halls, etc.; $\frac{10}{10000}$ bad for long and fair for short sessions. Beyond $\frac{12}{10000}$ for long, and $\frac{15}{10000}$ for short, should not be tolerated.

The amount of air supplied, though not a reliable indication of the efficiency of the ventilating work done by it, may be taken as an approximate test of the cause — as between the two classes of causes under consideration — of odor in a room or building. Thus 3,000 cubic feet per hour per head for adults may, in general, be considered an adequate supply for perfect artificial ventilation of a building in which the cubic space per head does not exceed that amount; 1,800 cubic feet per head for long sessions as fair, and for short sessions good; 1,000 for long bad and for short fair; and less than 700 for long and 600 for short sessions should not be tolerated.

A crude estimate of air quality as dependent on a ventilating system may be made by noting the areas of inlet and discharge conduits *at their most contracted parts.* The velocity of flow through ventilating flues, through which air is not mechanically forced, seldom exceeds, and generally falls short of, 500 linear feet per minute; and the mere fact that

mechanical means are employed is in itself no warrant of better results, since they may serve as a cover for egregious blunders. A velocity of 300 feet per minute is, in general, nearer the actual than 500. In flues of not less than one square foot cross-section the area of most contracted part must then be, roughly, 24 square inches for 3,000 cubic feet per hour per head, 16 for 1,800, 8 for 1,000, and 5 for 600. In smaller flues the areas must be greater.

If an odor persists in a room or building when carbonic acid gas is found to be at or below $\frac{8}{10000}$, its cause must be traced to some other source than inadequate air supply, and may then be sought in the presence of offensive matter about or within the building, or about the persons or clothing of those occupying it, or in the faulty local ventilation of some offensive premises, as water-closets, or clothes-closets, kitchen, drains, etc. The ventilation of such a premise should be such as to cause a strong and persistent movement of air toward and into it from adjacent rooms, rather than through and from it to them. To this end basement water-closets should be provided with close windows, self-closing doors, and an exhaust flue of sufficient strength and air-moving capacity to effect a strong in-current of air, and in such volume as to rapidly change the contained air of the inclosure.

In exceptional cases the air of an inclosure may be morbific without having any sensible odor, as by the presence of contagious or poisonous gas, dust or vapor, or in the presence of cold and absence of moisture, a condition retarding organic decomposition and putrefaction, and reducing the intensity of odors resulting from its presence. The sense of smell can, therefore, be regarded only as a sufficient evidence warranting further inquiry. In all questionable cases carbonic acid tests should be made, especially if olfactory is confirmed by ocular evidence; and in cases of suspected contamination not to be determined by either of these methods, the matter should be immediately referred to a sanitary expert or health board.

NOTES ON THE STRUCTURE OF THE QUILLS OF THE PORCUPINE.

BY EDWARD G. GARDINER, PH.D.

THE hair and quills of the common North American porcupine (*Erethizon*) presents some marked peculiarities. The back and sides of the animal are covered by long shaggy hairs, varying in color from brown to black, and frequently tipped with white.

These hairs are quite coarse, and often from 4 to 5 inches in length. The head, limbs, and belly are clothed with much shorter hairs, which

are generally of the same color as the long ones, except that they are seldom tipped with white. On the back and rump, interspersed with the long hairs, are numerous long, slender quills, which, unlike the hairs, are white in color, tipped with black. These quills are about one twenty-fourth of an inch in diameter throughout their entire length (4 or 5 inches) till within one quarter of an inch or so of the extremity, at which point they decrease rapidly in size, terminating in an exceedingly fine point. These quills, which are easily bent or broken, constitute but a small portion of the protective armament of the porcupine. The animal is further provided with very numerous short and exceedingly stout quills, from 1 to 2 inches in length, and of about twice the diameter of the long and slender ones. Like these latter they are white, and somewhat resemble the shaft of a feather in appearance. On the head, back, and sides these short quills are very numerous, although partially concealed by a thick growth of hair, such as clothes the limbs and ventral side of the body. On the tail, however, the quills are more numerous, and as the hair is much shorter, the quills are evident to the most superficial glance.

It is well known that when disturbed or irritated, the porcupine erects the hair and quills, at the same time striking at its assailant with its powerful tail. In the act of striking, when the tail is suddenly arrested by coming violently in contact with some obstacle, the shock is frequently sufficient not only to detach some of the quills, but to throw them a short distance. It is stated on good authority that the muscular contraction by which the quills are erected may cause some of them to be detached and ejected.

The manner of growth of the quills explains why some of them are so easily loosened. The quill, like an ordinary hair, grows from a papilla, which fits into the cup-shaped depression of the root (Figs. 1 and 2), and which lies imbedded in the *cutis vera*.

Fig. 1 shows the root of an immature quill enlarged about 15 diameters, the point of which protruded about one half an inch. There is no difference in size between the root and the part which is immediately above the skin. At this stage in its development the quill is very firmly attached, requiring considerable force to pluck it out. Fig. 2, on the other hand, shows the root of a full-grown quill which was detached by a slight shock. It will be seen that the root has in a measure atrophied, being less than half the diameter of the actively growing quill. In other quills which have dropped out the bulb (*a*) at the root is even smaller, and shows evidence of even further degeneration.

If the rate of growth during the formation of the whole quill is uni-

Fig 1

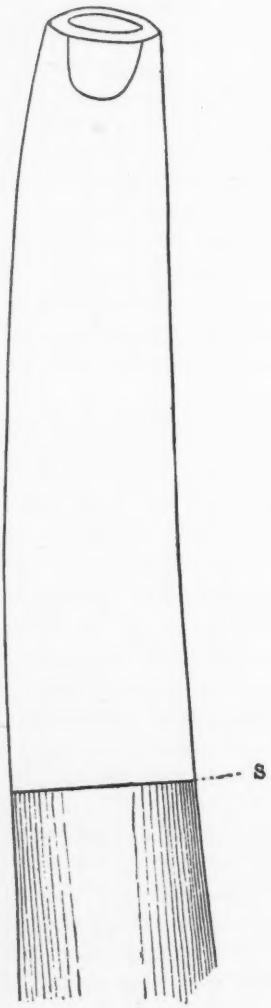


Fig. 2.

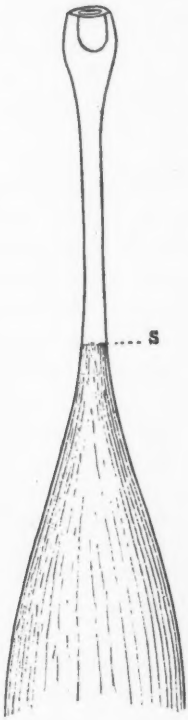
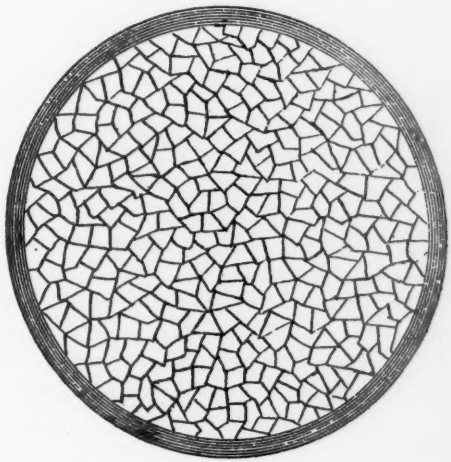


Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.



form, it is evident that when the part immediately below the line (*s*) was formed the papilla must have been undergoing very rapid diminution in size. Quill-roots showing different stages of degeneration have also been observed. The structure of the attenuated part of Fig. 2 is closely similar to that of the rest of the quill,— the principal difference being that the former is much less horny. In quills treated with picro-carmine this is the only part which takes the red stain. During the growth of the slender part, the papilla not only changes in size, but also in position.

In the young quill, which projects but one half an inch or so above the skin, the root is very deeply imbedded in the subcutaneous tissues. When, however, the papilla begins to dwindle it also begins to change its position, by growing up toward the surface; hence at the same time that the quill is being forced out by growth from the papilla at its base, the papilla itself is also traveling upward. The root of a young quill is often buried in the *corium* a quarter of an inch deep, while that of one which has reached its maximum development is seldom imbedded to half that extent. The letter (*s*) in the Figs. 1 and 2 shows the point up to which the quills were imbedded.

When the quill is fully developed it loosens itself and drops out. Whether the papilla which has borne it then dies, or whether it proceeds to build a new quill, is somewhat uncertain, though it would appear that the latter is the case. Young quills, the points of which are hardly above the surface of the skin, have their papillæ so close to the surface, that the thought that the papillæ are the ones which have just shed their quills naturally suggests itself.

It should be remarked here, that owing to the exceeding hardness of the quills great difficulty in obtaining sections fit for microscopic examination was experienced. The quills themselves can be cut only after prolonged treatment with caustic potash. From such sections as have been obtained, however, it would appear that after the quill had fallen out or been shed, the papilla begins immediately to build a new quill, at the same time sinking deep into the *corium*, as before described.

When the point of the quill is first thrust above the surface of the skin it is perfectly smooth and quite soft, being easily bent. As it grows longer it seems to dry up, and become much harder and stiffer. At the same time small plates appear on the surface, and shortly afterward these plates assume the form of barbs (Figs. 3 and 5).

These figures are from camera drawings of quills magnified about 15 diameters. Some idea of the exceeding sharpness of their points may be gained by comparing them with Fig. 4, which represents the extremity of a No. 12 sewing-needle magnified to the same extent. No. 12 is nearly, if not quite, the smallest sewing-needle that is used.

The quills are not solid in structure except near their points. In cross sections, as in general appearance, they very much resemble the shaft of a feather. Fig. 6 shows a section magnified about 60 diameters. There is an exceedingly hard, stiff cortical part, which is composed of flattened, fusiform horn cells. To separate these cells so that they are visible, treatment with caustic potash is advisable. Within this harder outer layer is the medullary cavity, which is generally filled with large pith-like cells. For the most part all traces of the original contents of these cells has disappeared, though occasionally oil or fat drops are present.

QUARTZITES AND SILICEOUS CONCRETIONS.

BY W. O. CROSBY, S.B.

THE preparation of this paper was first suggested to me by certain phenomena observed on Box Elder Creek, in the Black Hills of Dakota. The Potsdam beds in the cañon of this stream, as at most points where they are exposed in the Black Hills, rest with a gentle inclination upon the nearly vertical Archæan slates, and are overlaid conformably by the Carboniferous limestones. The thickness of the Potsdam is about 250 feet, varying with the unevenly eroded Archæan surface upon which it was deposited, and the hollows of which were filled up by its basal beds. These basal members of the Potsdam are extremely variable when traced from place to place, changing rapidly from the prevailing normal sandstone, sometimes to strata that are highly calcareous or rich in glauconite, and again to conglomerate masses in which water-worn boulders several feet in diameter are not uncommon. The basal sandstone is also often a firm quartzite.

There are many points in the northern Hills where the Potsdam is not observed to rest directly upon the Archæan, but its lowest exposed strata are underlaid by intrusive sheets and laccolites of rhyolite and other acid lavas. The intrusive sheets vary greatly in thickness, and have often been injected at several different levels in the Potsdam, giving repeated alternations of igneous and sedimentary strata. There are also numerous dikes connecting the intrusive sheets. Around the laccolites the Potsdam beds are usually upturned, sometimes at sharp angles, forming concentric lines of outcrop encircling the igneous cones, by which they have been locally metamorphosed. In fact, the Potsdam in the vicinity of the igneous masses (laccolites, sheets or dikes), and when not distinctly argillaceous,

calcareous or glauconitic, is always a hard vitreous quartzite, and often highly mineralized, forming the contact ore deposits of the Ruby Basin and other districts.

The Potsdam sandstone of the Black Hills varies, as a sandstone, from an almost incoherent mass of siliceous grains, crumbling on exposure and easily crushed in the hand, to a tolerably dense and compact sandstone, which in weathering forms cliffs. The colors vary with the nature of the cementing material from a light gray to a dark-brownish red; and the lighter kinds, especially, sometimes seem to pass gradually into quartzite, the siliceous grains becoming imbedded in a bright, glassy, siliceous cement.

As Newton has so clearly indicated,[1] "one of the most interesting points in the lithological structure of the Black Hills is the occurrence of beds of quartzite both at the base of the Potsdam and interstratified with its sandstones. Near Warren Peaks, Crow Peak, Terry Peak and other igneous masses, quartzites have been formed from sandstones by the direct metamorphic action of the volcanic outbursts; and in other portions of the Hills there are quartzites at the base of the formation which may possibly be the result of metamorphism accompanying the uplift of the Hills. But in many places throughout the Hills beds of hard, compact quartzite are found interstratified with the ordinary soft sandstones. Some of these localities are far removed from any evident locus of igneous action; and, indeed, the change of particular strata into quartzite while the overlying and underlying beds of sandstone are unaffected, is an occurrence which can scarcely be explained upon an igneous theory."

Similar conditions are not unknown elsewhere among the numerous Potsdam areas of the West, but nowhere, perhaps, are the facts so clearly exposed for study as in the Black Hills. The valley of Box Elder Creek presents, apparently, from this point of view, an exceptionally typical section of the Potsdam strata. The basal beds, as already indicated, are here a typical quartzite; while near the top of the formation a cliff of reddish sandstone, thirty feet in height, exposes numerous intercalated strata of hard, glassy quartzite, from six inches to several feet in thickness. It is also plain that some of the exposures of the Potsdam beds, from which the Carboniferous limestone has been removed by erosion, often owe their preservation to a thin but intensely hard sheet of quartzite.

Besides the continuous layers of interbedded quartzite, there are numerous discontinuous masses, one to several inches in thickness, and having the form of very thin, sharp-edged lenses of highly glassy quartzite scat-

[1] U. S. Geol. Survey, Report on the Geology and Resources of the Black Hills of Dakota, by Prof. Henry Newton, 1880, pp. 88-89.

tered through the granular and almost friable sandstone. These conform with the bedding of the sandstone, and are almost as sharply defined as the nodules of chert in limestone. In their smallest developments the quartzite lenses are minute flecks and shreds of the vitreous cementing silica, enveloping only a few grains of sand. Except that the cement is mainly vitreous instead of chalcedonic, and envelops the original water-worn grains of quartz instead of excluding them, it is strongly suggestive of the siliceous segregations of calcareous strata. The thin films or crusts of quartzite, described by Irving and Van Hise[1] as occurring on the weathered surfaces of the Potsdam and St. Peter's sandstones of Wisconsin, were distinctly observed on Box Elder Creek.

In discussing the probable origin of the interbedded quartzites, Newton rightly emphasizes their isolation by considerable thicknesses of entirely unaltered sandstone and shale. He clearly saw, as the following quotation shows, that this significant fact effectually bars out the usual igneous or hydrothermal hypothesis. "If only the basal member of the series assumed this character, it would be easy to suppose that there was some metamorphic action proceeding from below. But no such explanation will apply to the interstratified quartzites. If we suppose them to have been formed by igneous induration, even accompanied by heated waters, the unchanged condition of the intermediate and adjacent sandstones cannot be accounted for; and the uniformity of the quartzites in thickness, and their marked separation from the associated common sandstone, are equally difficult to understand. The quartzitic layers are sometimes separated by over one hundred feet of unchanged sandstone from the underlying schists, while even the basal conglomerate has not been metamorphosed in the least particular. In sections of the Potsdam, also, where the relations to the underlying schists are the same, and where there is no evidence of greater igneous action in the one case than in the other, the sandstones of one exposure will contain numerous beds of quartzite and those of another none."[2]

Professor Newton then goes one important step further, and plainly indicates what appears to be the only entirely satisfactory explanation of the interbedded quartzite, as follows: It is due to the gradual segregation, through the ordinary slight changes of temperature and pressure, of the soluble silica which, in the form of diatoms, sponge spicules, etc., was an original constituent of the formation, the layers of siliceous cement growing somewhat after the manner of layers and nodules of flint and chert. These microscopic siliceous organisms occur most abundantly in chalk and

[1] U. S. Geol. Survey, Bulletin No. 8, 1884, by R. D. Irving and C. R. Van Hise.
[2] Geology and Resources of the Black Hills of Dakota, pp. 92, 93.

other forms of limestone; and Newton's view of the origin of the interbedded quartzite derives additional support from the fact that the Potsdam sandstone of the Black Hills is often distinctly calcareous. There appears to be no good reason for regarding the basal quartzite as essentially different in either character or origin from the interbedded quartzite. It has been convenient to refer to them separately, simply because the evidence of a non-igneous origin is less conclusive for the basal than for the interbedded quartzite.

The Potsdam quartzites of the Black Hills thus fall naturally into two classes. (1) The quartzites associated with, and almost co-extensive with, the igneous rocks. These may be regarded as representing the metamorphism of the sandstone by the thermal and alkaline waters accompanying and following the intrusion of the volcanic materials. The cementing silica has probably been derived partly from the original organic siliceous constituents of the sandstone, but very largely, also, from the decomposition of the volcanic rock itself. (2) The interbedded (and probably, also, the basal) quartzites occurring beyond the influence of the volcanic action, and in entirely undisturbed portions of the stratified series.

A limited microscopic study of these two types of quartzite shows some structural differences. In the contact or igneous quartzites, as in the old Archæan quartzites, which are such a prominent feature in the geology and topography of the Hills, the grains are angular and fit accurately without visible interstices, the interstitial or cementing silica having, as has been so clearly shown by Irving, Van Hise,[1] and others, been deposited in optical or crystallographic continuity with the original grains of quartz, which are thus extended into accurately fitting and interlocking areas. Thin sections of the interbedded quartzite from Box Elder Creek, on the other hand, show rounded grains, essentially similar to those of the unaltered sandstone, and often coated with films of iron oxide, etc.; while the cementing silica, although partly in the form of minute, independently oriented crystalline grains, is chiefly chalcedonic or hyaline. It fills the insterstices between the grains as water would, and is not crystallographically continuous with them. Irving and Van Hise have figured sections not unlike those afforded by the quartzites of Box Elder Creek.[2] The more extended observation of Caswell,[3] however, show that the interbedded and basal quartzites are usually, like the contact or metamorphic quartzites, cemented by vitreous silica in the form of secondary enlargements of the original grains, each enlarged grain being, but for the inclosed

[1] U. S. Geol. Survey, Bulletin No. 8, 1884.
[2] Ibid. plate VI. [3] Geology and Resources of the Black Hills of Dakota.

foreign matter, optically uniform, angular, and accurately interlocking with the adjacent grains.

That the segregation of the original organic and amorphous silica, under the normal conditions of an undisturbed sedimentary series, may yield a highly vitreous or crystalline form of quartz, is proved not only by the observations of Irving and Van Hise on the Potsdam and St. Peter's sandstones of Wisconsin, in which there seems to be no other sufficient source of soluble silica, but also, and more clearly, by the abundant and perfect crystallizations of quartz in flint, chert, geodes, and other siliceous segregations. Nodules and layers of chert not only inclose crystalline druses, but the chert itself sometimes passes insensibly into granular, vitreous quartz, not easily distinguished from typical quartzite. Such cherts are described by Irving and Van Hise, and have been observed by the writer in the Silurian limestones of East Tennessee.

That the twofold origin of the cementing silica indicated by the modes of occurrence of the Potsdam quartzites of the Black Hills is a general fact there can be but little doubt. The abundant deposition, in the form of mineral veins and siliceous tufa, by thermal and alkaline waters, of silica which must have been derived from the decomposition of alkaline silicates, shows that in the neighborhood of eruptive masses, and generally at considerable depths, silica having this hydrothermal or purely chemical origin must often exist abundantly in the waters percolating through the arenaceous rocks. On the other hand, it is a well-established fact that microscopic siliceous organisms — Diatoms, Radiolaria, etc. — exist in all parts of the sea, and in nearly all natural waters; and consequently they must form a part of nearly every kind of sediment. The supposition, therefore, seems warranted that, even in the arenaceous rocks, this minutely divided, soluble, organic silica must sometimes be sufficiently abundant to explain, by its solution and re-deposition, their conversion into quartzite As already stated, this explanation of the siliceous induration of sandstones appears to be peculiarly applicable to interbedded and isolated quartzites in undisturbed formations, remote from volcanic sources; and we may suppose that in sandstones which have not experienced the quartzite alteration the organic silica occurs so sparingly as not to form a saturated solution with the interstitial water, except near the surface, where evaporation lends its aid to the formation of the quartzite crusts described by Irving and Van Hise.

It will, I think, be generally conceded that this principle of classification according to the source of the silica may be properly extended from the cement of the quartzite to the various more concrete forms of segregated silica, such as the nodules, geodes, veins, druses, incrustations, etc.

of flint, chert, chalcedony, agate, jasper and the many other and more crystalline forms of quartz. When these are associated with eruptive or metamorphic rocks, and, more generally, when they occur under conditions which indicate that the silica has been derived directly from the decomposition of silicates by thermal or acidulated waters, as in the case of the great majority of the veins, pockets, and incrustations of crystalline quartz, chalcedony, agate, jasper, etc., they are evidently connected in origin with the contact or metamorphic quartzites; while the nodules, geodes, etc. of flint, chert and other kinds of silica observed in unaltered sediments, and especially in calcareous strata, are clearly related in origin to the interbedded quartzites.

It is not my purpose to discuss any further at this time the origin and relations of the contact or metamorphic quartzites, or of what may be called the purely chemical segregations of silica. Nor does it appear necessary to my main object to consider in detail the mode of formation of the segregated forms of silica observed in calcareous and other undisturbed sedimentary strata. Few of the minor problems of geology have received more attention at the hands of both geologists and mineralogists than the origin of the nodules and other forms of flint, chert, etc.; and it would be sufficient, so far as the relations of these segregations to the interbedded quartzites are concerned, to simply follow Geikie and other standard authors in attributing them to the solution and redeposition of the widely and abundantly distributed organic silica. A still recent contribution to this subject by Prof. W. J. Sollas[1] is, however, so able and comprehensive, that we may, perhaps, profitably digress long enough to notice some of his more important conclusions, and to follow up one or two suggestions to which they give rise.

The investigations of Professor Sollas have led him to regard the organic origin of the silica as an almost self-evident truth. The ready solubility of the siliceous organisms under natural conditions has been placed beyond reasonable doubt by numberless observations. Professor Sollas considers that we have still much to learn concerning the precise nature of the solvent. This is probably not always the same; and he makes the fertile suggestion that, while the conditions must often be favorable for the action of the humic acids and the albuminoid or glairy substances to which Julien attaches so much importance, it is probable that the organisms are often dissolved by the water alone, in the depths of the sea and in deeply buried sediments, where its solvent power is augmented by pressure.

[1] On the Flint Nodules of the Trimmingham Chalk, by Prof. W.J. Sollas, Annals Nat. Hist., 1880, pp. 384–395; 437–461.

In attributing the solution of the siliceous organisms and the re-deposition of the silica to the slight oscillations of the chemical and physical conditions which must always be in progress, we are not in effect saying that the same portion of silica may be dissolved and redeposited many times in succession. Professor Sollas very properly emphasizes the plain fact that the silica which passes into solution is a very different thing from that which has passed out of solution. He calls the one *organic*, and the other *mineral* silica. The two forms are strongly contrasted in their solubilities, as well as in other chemical and physical characters; and hence segregation in this case means a solution of soluble organic silica and a deposition of insoluble mineral silica, and not a solution and deposition of the same kind of silica. In this connection he points out that the dissolved silica is deposited not only in the relatively insoluble forms of flint, chert, chalcedony, etc., but also in the almost absolutely insoluble form of crystalline quartz, as in geodes, etc., and in the perfect microscopic crystals disseminated in vast numbers through various forms of limestone. These microscopic crystals undoubtedly represent the independently oriented crystallizations of the cementing silica in quartzites.

One of the most important and interesting facts observed in connection with the siliceous segregations in sedimentary rocks, is the very common occurrence of the segregated silica as a pseudomorph after calcium carbonate. The power of a dilute solution of colloid silica to replace calcium carbonate has been experimentally demonstrated by Prof. A. C. Church,[1] who has actually converted a coral into silica by this means. The ordinary solid nodules of flint and chert present a fairly clear case of this pseudomorphism, since we can rarely doubt that room has been made for the segregating silica by a concomitant solution of the imbedding chalk or limestone. The evidence is much stronger, however, with silicified fossils; and the abundance in many limestones of shells, crinoids, corals, etc. which have been replaced by silica shows that calcium carbonate which still retains the organic form and structure is peculiarly liable to this replacement. It is doubtful if the substitution is usually so perfect, so nearly molecule for molecule, as in silicified wood. This is especially obvious in the geodes and similar forms, in which the silica only partially fills the space which must have been previously occupied by calcium carbonate. It is plain in such cases that the solution of the calcium carbonate proceeded more rapidly than, if it did not entirely precede, the deposition of the silica in the solid form. There could scarcely be a more instructive illustration than is afforded by the chalcedonized coral occurring in the Tertiary beds of Tampa Bay, Florida.

[1] Chemical News, V., 95; Jour. Chem. Soc., XV., 107.

These interesting specimens, as all mineralogists know, are usually thin, hollow shells or geodes of translucent chalcedony, which are generally handsomely botryoidal, although occasionally finely crystalline or drusy, on the inner surface, while preserving the form of the coral very perfectly externally. As the inner, botryoidal surface suggests, the chalcedony has been deposited in layers parallel with the uneven exterior; and it is itself devoid of organic structure. The history of these geodes, which are externally but silicified casts of the corals, has evidently been something like this: The masses of coral, after becoming imbedded in a stratum of marl, were completely removed by solution before the deposition of silica in the solid form began in the molds thus formed. Accepting the view of Professor Sollas that the silica has been an active and necessary agent in bringing about the solution of the coral, we can scarcely escape the conclusion that the segregation of the silica was contemporaneous with the process of solution. This involves the further conclusion that during the solution of the coral the solution of the associated siliceous organisms was also taking place; and this dissolved silica was steadily accumulating, probably in a pectous or gelatinous condition, in the molds left by the coral. Subsequently the silica, commencing externally, gradually passed from the pectous to the solid state, the last portions to solidify forming the inner surface of the geode, and very often assuming a crystalline form.

We have here, perhaps, a glimpse, at least, of the secret of the geode; and can almost grasp the explanation of the fact that some siliceous segregations are solid and others hollow. Nodules of flint and chert, and the ordinary geodes of limestone strata, alike represent the gradual replacement of globular masses of limestone or chalk by equivalent portions of pectous silica. The main point of difference is, that in the solid segregations the silica passed from the pectous to the solid form as fast as it accumulated, and the nodules grew from the centre outward; while in the hollow segregations the solidification of the silica did not, for some undetermined cause, begin until the replacement was complete,— *i. e.*, until all the available organic silica had been dissolved, concentrated through its tendency to replace calcium carbonate, and thus reduced to the pectous state, and the geodes, consequently, grew from the circumference inward.

A precisely similar contrast may be traced between the ordinary silicified fossils and the silicified coral of Tampa Bay; the replaced calcium carbonate being in both cases in the form of entire organisms instead of massive limestone (fragmental organisms), and the solidification of the replacing silica being contemporaneous in one case and subsequent in the other. The water with which the unbroken coralline geodes of Florida are often partially filled may, apparently, be usually regarded as the water

that would necessarily be excluded and left behind during the passage of the silica from the pectous to the solid or crystalline state.

Returning now to the further consideration of the relations between these various forms of siliceous concretions and the interbedded quartzite, and accepting the postulate that the cementing silica of the latter shares the organic origin of the segregating silica of the former, we have first to notice the normal distribution of the organic silica in different classes of sediments. Recent investigations have shown that such pelagic siliceous organisms as the Diatomacea and Radiolaria inhabit the surface waters of nearly all parts of the ocean. On the death of the organisms, their tests or hard parts slowly sink through the still waters; and the examination of the various kinds of marine sediments now in process of formation has shown that this quiet rain of organic silica is falling upon the ocean floor in all latitudes, and alike in the deepest and the shallowest parts of the sea, over the marginal zones of rapid deposit, as well as over the abyssal areas where deposition is almost at a stand-still.

The organic silica is naturally a much more conspicuous feature of the deep sea oozes and clays, which are accumulating with extreme slowness, than of the terrigenous sediments, which are being spread with comparative rapidity over the shallower and more marginal portions of the sea floor. If, for example, the time required for the deposition of one inch of pure organic silica would permit the accumulation of one foot of deep-sea ooze and of one hundred feet of mechanical shore sediments, it is plain that while the inch of silica would form an appreciable and even important fraction of the former, it would be an entirely insignificant constituent of the latter, being diffused with inappreciable thinness through the great mass of land detritus. We are justified, therefore, in concluding that the organic silica must in general form a rapidly increasing proportion of marine deposits as we pass from the coarse gravels and sands of the shore lines across the finer sands and clays of the marginal zone to the purely calcareous sediments, the organic oozes, and the red clay of the abyssal areas. Assuming a uniform distribution of the siliceous organisms along a line from the shore seaward, and it is obvious that their conspicuousness will be inversely proportional to the rate of deposit of the associated sediments.

Subsequently to its deposition, the organic silica, as already indicated, passes largely into solution, and under favorable conditions is redeposited in a more insoluble form. We seem at liberty to suppose that the solution and segregation of the silica often follows closely upon its deposition; but in other cases it is certain that it remains undissolved for considerable periods of geological time. Thus, this important change has not yet occurred to any appreciable or important extent in the great bed of dia-

tomaceous earth or tripolite which is such a prominent feature of the Miocene Tertiary of Virginia and Maryland.

The dissolved and redeposited silica takes the form of concretions, geodes, etc., or, when very abundant, of more or less continuous layers of flint, chalcedony, etc., in calcareous sediments, and of quartzite in arenaceous or mechanical siliceous sediments. The interbedded character of quartzites formed in this way, and the fact that they are often entirely wanting in extensive series of mechanical sediments covering wide areas, is readily explained, as already pointed out, by supposing that the original organic silica was insufficient to form a saturated solution with the interstitial waters. Thus in the Appalachian region, where the coarse, mechanical, Paleozoic sediments have a vast thickness and volume, and were evidently deposited so rapidly that the organic silica could never have formed more than an infinitesimal fraction of the whole, interbedded quartzites occur but rarely if at all; while in other regions, like the Black Hills, the Rocky Mountains, Wisconsin, etc., the Paleozoic, and especially the Potsdam, sediments, although often arenaceous, afford evidence in their fineness, uniformity, frequently calcareous or glauconitic character, and in their distances from the ancient shore lines, or from any abundant source of detritus, that they have been formed so slowly that organic silica may be regarded as a prominent original feature; and the arenaceous beds often exhibit the quartzitic alteration due to the segregation of this soluble silica. The non-metamorphic or interbedded quartzites are thus an indication of slow deposition,—of the formation of sandstones under physical conditions which, when life is more abundant, yield limestones.

The question arises at this point as to why the product of the segregation of the organic silica is chiefly quartzite in arenaceous sediments, and concretions of chert, etc. in calcareous sediments. The answer is, probably, to be found mainly in the selective action of the segregating silica,—in its innate tendency to deposit upon particles or surfaces of its own nature. Remembering that the redeposited silica is insoluble quartz instead of soluble opal, and it will be seen that in an ordinary quartzose sandstone every grain of sand is of like nature with the segregating silica, and affords a favorable centre or nucleus for its deposition. Hence, as Irving and Van Hise have shown, when the process of segregation is not too rapid, the secondary enlargement of the grains, in the attempt to reproduce the missing portions of the original crystals, is the natural result. The organic silica thus appears almost as completely dispersed after as before its segregation. We cannot, however, doubt that the interbedded layers of quartzite usually represent a considerable concentration of silica; and that the layers, like solid concretions, grow from the middle line out-

ward, by drawing in silica from the overlying and underlying portions of the sandstone. In calcareous sediments, on the other hand, the really favorable centres of segregation must usually be few and remote. Consequently larger volumes of sediment, and of sediment much richer in soluble silica, are tributary to the individual centres; and isolated concretions and geodes of sensible or large size are gradually developed.

MINERALOGICAL NOTES.

VESUVIANITE FROM NEWBURY, MASS.

BY W. O. CROSBY AND JAMES T. GREELEY.

THROUGH the kindness of Mr. J. H. Sears, we have received several specimens of a massive, brown mineral from the old lime quarries in Newbury known as the Devil's Den and the Devil's Basin. It is quite massive, the crystallization being indicated only by obscure cleavage planes. The hardness is not above that of orthoclase; and the specific gravity, which was kindly determined by Mr. T. T. Bouvé, is about 3.55, the determinations varying from 3.52 to 3.60. The lustre is imperfectly vitreous, and the color is the usual brown of vesuvianite. It fuses quite readily, and with intumescence, to a brownish glass. What appeared to be the purest and most homogeneous specimen, was analyzed by Mr. Greeley, with the following result: —

SiO_2	35.93	K_2O	.44
Al_2O_3	14.77	Na_2O	.36
FeO	8.91	MnO_2	trace
CaO	39.46	P_2O_5	trace
MgO	.13	CO_2	not determined
			100.00

An error of — .44 was proportionally distributed. It was probably due in part to water and the reagents, but mainly to the undetermined carbon dioxide. Calcite (and probably siderite) in the form of slight veins and threads, is present as a visible impurity in all the specimens; and it was found impracticable to obtain a sample wholly free from them. This explains the high percentage of lime as well as the carbon dioxide. The analysis agrees almost equally well with the lime-alumina garnet (grossularite); and this is, probably, the massive garnet mentioned by Dana as occurring in Newbury. The physical characters, however, as well as the mode of occurrence, ally it more closely with vesuvianite, which has not

heretofore been found in eastern Massachusetts. The chief associated minerals, besides the crystalline calcite or limestone, are serpentine and chrysotile, dolomite and bladed wollastonite. The largest and most typical specimen shows a vein two inches and a half wide, between walls of limestone or dolomite, in which two equal layers of green serpentine are separated by a very distinct and regular layer, one and one-fourth inches wide, of the compact vesuvianite, forming the middle of the vein. A thin section, under the microscope, exhibits the very feeble double refraction of vesuvianite, and innumerable minute veins of calcite.

GAHNITE, OR ZINC-SPINEL, FROM ROWE, MASS.

BY W. O. CROSBY AND CHARLES L. BROWN.

WHILE examining a lot of the massive pyrite from the great vein of this mineral in Rowe, attention was attracted to some hard, black crystals from one fourth to one half inch or more in diameter. The crystals are isometric; and several fairly-perfect examples were obtained, which show that they differ somewhat in the development of the planes. One specimen is a simple octahedron, while another nearly perfect crystal is a combination of two tetrahedrons slightly modified by the rhombic dodecahedron. Indistinct traces of octahedral cleavage were observed in broken specimens. Hardness, about 7.5; scratches both quartz and tourmaline. Specific gravity, determined by Mr. Bouvé, 4.54. Lustre, vitreous; color, black and streak gray, agreeing exactly in these properties with black tourmaline. A pure sample was analyzed by Mr. Brown, with the following result: —

$Al_2O_3 + Fe_2O_3$	58.05
Zn O	35.91
Insoluble residue	1.49
	95.45

Since the object of the analysis was simply to identify the mineral, no attempt was made to determine all the constituents. A comparison of this mineral with the different varieties of gahnite shows that while the physical properties and especially the pure black color appear to ally it with the kreittonnite of Bavaria, the composition, and particularly the high proportion of zinc oxide, relate it more nearly to the automolite of Franklin, N. J. The immediately associated minerals at the mine in Rowe, besides the granular pyrite, are chalcopyrite, sphalerite and quartz.

THE PROPER METHOD OF COMPARING THE COST OF CHILLED-IRON AND STEEL-TIRED CAR WHEELS.

BY GEO. F. SWAIN, S.B.

THE engineer — no matter what branch of the profession he may follow — is frequently called upon to consider and decide upon the relative economy of different classes of structures, appliances, or machines for accomplishing the same ends. Some of these may be much cheaper than others in first cost, but their life may be shorter, or the annual expense of maintaining them greater; and it not infrequently is a question of some complexity to determine properly which is, in the end, the most economical.

In deciding, for instance, upon the type of pumping engine to use in works of water supply, it is generally necessary to compare pumping engines giving different duties, and differing in first cost. In planning bridges or viaducts, the question is between a stone arch, costing a large sum but requiring little or no expense for maintenance; an iron bridge, costing much less, but liable to wear out or to be outgrown by the rapid increase in weight of rolling stock, and requiring some annual outlay for repairs and maintenance; and a temporary wooden bridge or timber trestle,— cheap, but short lived, and requiring constant attention. Again, in comparing chilled-iron with steel-tired car wheels, the same form of question appears, and the engineer will readily call to mind numerous cases where the same class of reasoning has to be made use of.

Problems of this kind are not always attacked in the same way, and erroneous conclusions are not infrequently met with, due to a neglect of some of the essential elements of the problem. Sometimes, as will presently be illustrated, we see two structures compared by simply finding the cost of the number of each necessary to last a given time; this being erroneous, because, among others, the question of interest is not considered. Sometimes we see two machines compared by finding for each the first cost plus the capitalized cost of maintenance; this being not strictly correct even when the machines have the same life, and are worth the same sum when worn out.

The object of this paper is to indicate what seems to the writer the proper method of viewing such questions, *supposing the necessary data to be at hand*, and to illustrate its application to the question of car wheels. It must not be supposed, however, that anything will replace a sound and far-seeing judgment. A completely correct solution of any problem

of this kind is complicated by a great variety of circumstances. The cost of materials of construction, of coal, of maintenance, is subject to variation; the rate of interest fluctuates, and the life of few structures or machines can be stated with absolute certainty. To the far-seeing mind, circumstances entirely aside from cost will sometimes, if not in the majority of cases, fix the class of structure to be adopted. Such considerations as the fact that rapid improvements in some branch of industry bid fair to lead to great economy in the manufacture of certain machines or implements; or the fact that possible changes in the location of a line of railroad may be found necessary or advantageous,—such considerations as these in many cases at once determine the class of structure to be adopted. Then again, the matter of cost is only one of the questions to be considered in determining upon any structure, and matters of safety, convenience, or time, may of themselves require a structure of a particular kind. Nevertheless, the question of cost should not be left out of consideration, and in discussing matters of this kind every possible aid to a proper judgment should be invoked. With this in view, the following reasoning may throw some light on the subject.

The problem, in its most general form, may be considered to be this: a certain structure or machine costs A dollars, it requires the expenditure of B dollars for repairs at intervals of s years, it will last for n years, and when worn out it may be sold for D dollars. A second structure or machine for accomplishing the same object costs A_1 dollars, requires the expenditure of B_1 dollars for repairs every s_1 years, lasts for n_1 years, and is worth D_1 dollars when worn out. Which of these will be more economical, as a permanent thing, the rate of interest being r, payable semi-annually?

To answer this question we must compute the amount of present capital sufficient to provide permanently for each of these structures, and the one which requires the smaller capital will be the more economical. Or we are enabled to find, by the same method, what the cost A_1 of a (perhaps new) appliance must be, in order that it may be more economical than a similar appliance in use, under various suppositions as to the life, cost of maintenance, etc.

The present capital required for any structure will be made up of three parts.

1st. A, the cost of the structure.

2d. A sum which, put at interest at r per cent, will increase in s years, by the amount B. This sum may easily be shown to be

$$\frac{B}{[(1+\frac{r}{2})^{2s}-1]}$$

r being expressed as a proper fraction ($r=\frac{6}{100}$ if the rate is 6 per cent).

3d. A sum which, put at interest at r per cent, will amount, in n years, to itself plus (A — D); since at the expiration of the n years, the worn-out structure being sold for D dollars, there will result a sum sufficient to again expend A for a new structure, and have the original sum remaining, which in another n years will amount to sufficient to purchase a third structure, and so on indefinitely. This sum is

$$\frac{A-D}{[(1+\frac{r}{2})^{2n}-1]}$$

The total present capital involved in the use of any structure is therefore

$$C=A+\frac{B}{[(1+\frac{r}{2})^{2s}-1]}+\frac{A-D}{[(1+\frac{n}{2})^{2n}-1]}$$

In certain cases the formula is simplified. Thus if D is so small as to be practically zero in comparison with the first cost of a new structure, and if B is the uniform annual cost of maintenance (supposed payable semi-annually) as in the case of a pumping engine, we have

$$C=A+\frac{B}{r}+\frac{A}{[(1+\frac{r}{2})^{2n}-1]}$$

which in A is the first cost of the structure or machine, and $\frac{B}{r}$ is the capitalized cost of maintenance. This result shows that it is not *strictly* correct, in comparing, as a permanent investment, let us say, two pumping engines which may be supposed of equal durability, to compare simply the first cost plus the capitalized cost of operation, since this omits the last term in the above formula. This term, however, when n becomes large, rapidly decreases, and in many cases may well be neglected.

The following table gives values of the quantity

$$X=\frac{1}{[(1+\frac{r}{2})^{2n}-1]}$$

for different rates of interest and different values of n. From the table the coefficient of B and of $A-D$ in the above formula may be taken out.

TABLE GIVING VALUES OF X FOR DIFFERENT RATES OF INTEREST.

3 per cent.		4 per cent.		5 per cent.		6 per cent.	
n	x	n	x	n	x	n	x
0.5	66.67	0.5	50.00	0.5	40.00	0.5	33.333
1.	33.112	1.	24.752	1.	19.762	1.	16.420
2.	16.287	2.	12.136	2.	9.634	2.	7.968
3.	10.706	3.	7.924	3.	6.381	3.	5.152
4.	7.905	4.	5.824	4	4.523	4	3.248
5	6.23	5	4.566	5	3.570	5	2.908
6	5.111	6	3.728	6	2.900	6	2.348
7	4.314	7	3.130	7	2.421	7	1.951
8	3.717	8	2.682	8	2.064	8	1.654
9	3.254	9	2.335	9	1.767	9	1.424
10	2.883	10	2.058	10	1.566	10	1.240
12	2.328	12	1.644	12	1.236	12	0.968
14	1.933	14	1.349	14	1.003	14	0.776
16	1.638	16	1.130	16	0.831	16	0.635
18	1.410	18	0.962	18	0.698	18	0.527
20	1.228	20	0.828	20	0.593	20	0.442
22	1.081	22	0.719	22	0.509	22	0.374
24	0.958	24	0.630	24	0.440	24	0.319
26	0.855	26	0.555	26	0.383	26	0.281
28	0.768	28	0.493	28	0.335	28	0.236
30	0.693	30	0.439	30	0.294	30	0.204
35	0.545	35	0.333	35	0.216	35	0.144
40	0.436	40	0.258	40	0.161	40	0.104
45	0.353	45	0.202	45	0.121	45	0.075
50	0.291	50	0.160	50	0.092	50	0.055
55	0.241	55	0.128	55	0.071	55	0.040
60	0.201	60	0.102	60	0.054	60	0.030
65	0.169	65	0.082	65	0.042	65	0.022
70	0.142	70	0.067	70	0.033	70	0.016
75	0.120	75	0.054	75	0.025	75	0.012

As an example in the use of this table, we will consider the economy of chilled-iron as compared with steel-tired car wheels, under different suppositions as to life and first cost. This problem is a very simple one, yet in discussing it erroneous figures and conclusions are the rule rather than the exception.

One method, sometimes used by wheel manufacturers and others in comparing these different kinds of wheels, may be illustrated as follows: Suppose that a chilled-iron wheel costs $10 and a steel-tired wheel $50, but that the latter will last as long as ten of the former. Then we have ten wheels at $10, or $100, as against one wheel at $50,—or "a saving of $50 in favor of the steel-tired wheel." Clearly, this method of comparison is entirely incorrect, neglecting as it does the question of interest. If one steel-tired wheel lasted only as long as five chilled-iron wheels, this

method would give the same economy for both; whereas it is evidently cheaper to pay $10 yearly than to commence by paying $50, continuing the same payment once in five years. Then, again, the scrap value of the wheels is neglected by this method.

A second method, very commonly used by engineers in other comparisons, is to compare the first cost plus the capitalized cost of maintenance. Thus, supposing that one structure costs $100 and will last five years at an annual expense of $5, then this annual expense at 5 per cent is the interest on $100, which, added to the first cost, gives a total of $200. If, now, another structure costs $60 and will also last five years at an annual cost of $7, the sum obtained is $200, as before, so that according to this method of calculation, the two structures would be equally economical. But it will be evident that in the first case we should be paying $100 down and $5 a year for five years, or, in all, $125 in five years, while in the second case we should be paying $60 down and $7 a year for five years, or in all, $95 in five years. The second structure is, therefore, in reality much more economical than the first, and the method of computation is shown to be fallacious. It is, in fact, only correct when the duration of each of the structures compared is infinite, as already remarked.

The problem becomes still more complicated when we come to consider the effect of the sum which can be obtained for the worn-out wheel; yet even in taking account of this, one or the other of the methods indicated above is generally used. Thus, according to the first method, we may figure the first cost plus the cost of all repairs or alterations made during the life of the wheel, and then deduct its scrap value. This, however, will of course be again incorrect by reason of the neglect to consider the question of interest.

The question is sometimes, though rarely, discussed correctly, although by a method somewhat different from that proposed in this paper, as follows: suppose that a steel-tired wheel costs $50, and requires the expenditure of $2 every two years, until at the expiration of ten years it is worn out, and is sold as scrap for $10. Find now the sum which $50 would amount to in ten years, at the assumed or current rate of interest; also what $2 would amount to in eight years, plus what a second $2 would amount to in six years, a third in four, and a fourth in two years; from this total sum deduct the scrap value of the wheel, and the remainder will represent the total cost of that wheel, with interest; and this can be directly compared with the cost of another wheel, *for the same length of time*. This method is used by some railroads in studying the comparative economy of different kinds of wheels. It is, however, not so easy in its application as the one herein proposed.

For purposes of illustration, let us now start with some figures regarding the cost and mileage of chilled-iron wheels. These wheels cost from seven or eight up to thirteen or fourteen dollars each. They give a mileage which varies very greatly according to the quality of the wheel and the character of the service put upon it. Under passenger equipment it is claimed, on the one hand, that wheels of good quality will not give a mileage of over 30,000 miles; while, on the other hand, some claim that wheels of this kind have been known to run 400,000 miles. Under freight equipment the mileage should be somewhat greater than under passenger equipment, since the wheels are not so apt to be worn flat by sliding, caused by the application of the brakes, and since it is not so important that a wheel should be perfect. Again, the actual mileage of a wheel is not what is required in making a comparison of this sort,—it is the *length of time* the wheels last, which will depend upon the average daily mileage of the cars. This, also, varies greatly according to the circumstances of the case, such as whether the wheels are used for local traffic, making frequent stops, or whether they are run on through express trains for long distances, etc.

Let us assume, now, two classes of chilled-iron wheels, viz.:—

I. Cost \$10 ($= A$).
Value of scrap, \$5 ($= D$).

Average mileage, 30,000 miles, or say one year, at about eighty miles a day.

Cost of removing old wheel and fitting new one, \$1.

II. Cost of wheel, \$12.50 ($= A$).
Value of scrap, \$6 ($= D$).
Mileage, 60,000 miles, or say 2 years.
Cost of removing and fitting, \$1.00.

Now by the use of the table it will be found that the capital necessary to furnish forever one of these wheels is, at 4 per cent interest: —

For Class I., \$159 50.
For Class II., \$104.50.

Let us now compare these with several classes of steel-tired wheels, by finding how much could be paid for such steel-tired wheels to make them equally economical with the chilled-iron wheels; that is, using the same capital in both cases. We will consider the following four categories of steel-tired wheels: —

(*a*) A wheel which is not to be re-tired, but in which the wheel and tire are welded together, so that when the tire is worn out the wheel

must be replaced. We suppose that the mileage of such a wheel is 240,000 miles, but that after each 60,000 miles the tire must be turned down and made true, at a cost of $1, which is a very low figure. The worn-out wheel will be worth about $10. We therefore have in our formula, $B = \$1$; $s = 2$; $D = \$10$; $n = 8$,— supposing 30,000 miles to be traveled in a year.

(*b*) As a second class, take a wheel of the same kind, but which runs 120,000 miles to a turning, or 480,000 miles in all. In this case we have, $B = \$1$; $s = 4$; $D = \$10$; $n = 16$.

(*c*) As a third class, take a wheel whose centre is indestructible, but whose tire is to be renewed at intervals. Suppose it bears 4 turnings at 60,000 miles each, or 240,000 miles in all, equivalent to 8 years.

Cost of turning, $1 every 2 years.
Cost of re-tiring, $30 every 8 years.

Here we have, $B = \$1$; $s = 2$; $D = 29$ (since we have already allowed $1 every two years); $n = 8$.

(*d*) Finally, suppose a wheel to be re-tired; centre indestructible; 5 turnings at 90,000 miles, or three years' service for each turning.

Total mileage, 450,000 miles — 15 years.
Cost of turning, $1 every 3 years.
Cost of re-tiring, $50 every 15 years.

The following table gives approximately the price which could be paid for steel-tired wheels of the four classes, to make them equally economical with the cast-iron wheels, interest being reckoned at four per cent: —

Class of Steel-tired Wheel.	Class of Cast-iron Wheel.	
	I.	II.
A	$47.00	$32.00
B	77.00	51 00
C	69.00	13.60
D	90.00	36.00

A further study of this question will show very clearly that small differences in the assumed data will make very considerable differences in the results obtained. For instance, we have taken the cost of turn-

ing a steel-tired wheel at $1. Probably in the majority of cases it costs more, and in many cases double or treble that amount. If we suppose, now, with wheels of class *a*, that the cost of turning is $2.50 instead of $1, we shall obtain, for the price which could be paid for them, $42 and $27, instead of $47 and $32 respectively. The results obtained by taking $1 as the cost of turning are, of course, in favor of the steel-tired wheels, and from the table some general conclusions may be drawn.

In the first place, since the cost of steel-tired wheels is generally above $50, it is clear that a cast-iron wheel of class 2, *i. e.*, one which, costing $12.50, would last for a period of two years, would be considerably more economical than any of the steel-tired wheels considered, excepting those of class *b*, of which the mileage is assumed to be 480,000. This average mileage, however, has not as yet been attained, the average upon one road which uses them extensively being about 270,000 miles. On the other hand, as already stated, while some excellent authorities claim that the mileage of good cast-iron wheels, under passenger traffic, will not exceed 30,000 miles on the average, other authorities state that it will run up to 50,000 or 60,000 miles.

It cannot, therefore, be stated absolutely that cast-iron wheels are cheaper than steel-tired wheels, or the reverse. Some kinds of cast-iron wheels may be cheaper than some kinds of steel-tired wheels, and the reverse is also true. But while the element of cost is one which should of course be considered, there are other and more important ones affecting the choice of a wheel, such as safety and convenience. Clearly, the difference in cost is not such as to override these questions.

PRESSURE OF SATURATED STEAM.

BY C. H. PEABODY, S.B.

IN the preparation of notes on thermodynamics it appeared advisable to calculate anew the constants for Regnault's equations for saturated steam, using such refinement that a reinvestigation of the subject would not be required. In this article the data and calculations will be given at length, together with the reduction to the English system of units, and a calculation of the constants for equations giving the first differential co-efficient.

The subject was taken for a graduation thesis by Mr. C. B. Appleton, of the Class of 1884; and again by Messrs. A. S. Garfield and E. L. Pierce, Jr., of the Class of 1885, who recalculated the constants for the equations, with results that do not differ widely from those given here.

As is well known, Regnault's experiments consisted essentially in taking the boiling point of the vapor under different atmospheric pressures, the apparatus being so arranged that the pressure could be varied from a small fraction of an atmosphere to more than twenty atmospheres. The temperatures were taken with mercurial thermometers, and after the necessary corrections were applied and temperatures were reduced to the scale of the air thermometer, Regnault selected the results he deemed most trustworthy and plotted a series of points, and then drew a smooth curve to represent the whole series of experiments. He then selected points on the experimental curve at regular intervals, and with the co-ordinates of these points as data he calculated the constants of empirical formulæ to be used in calculating tables.

The formula he selected had the form

$$\log p = a + b\alpha^n + c\beta^n, \qquad (1)$$

in which p is the pressure, and n is the temperature minus the constant temperature t_0 of the lowest limit of the range of temperature to which the formula applies; *i. e.*,

$$n = t - t_0.$$

Let the points through which the curve represented by the equation is to pass be (p_0, t_0), (p_1, t_1), (p_2, t_2), (p_3, t_3), and (p_4, t_4), so chosen that

$$t_1 - t_0 = t_2 - t_1 = t_3 - t_2 = t_4 - t_3.$$

$$\therefore\ t_2 - t_0 = 2(t_1 - t_0),\ (t_3 - t_0) = 3(t_1 - t_0),\ (t_4 - t_0) = 4(t_1 - t_0).$$

Substituting the five known values of p and t in equation (1),

$$\left.\begin{aligned}
\log p_0 &= a + b\alpha^{0} + c\beta^{0} \\
\log p_1 &= a + b\alpha^{t_1 - t_0} + c\beta^{t_1 - t_0} \\
\log p_2 &= a + b\alpha^{2(t_1 - t_0)} + c\beta^{2(t_1 - t_0)} \\
\log p_3 &= a + b\alpha^{3(t_1 - t_0)} + c\beta^{3(t_1 - t_0)} \\
\log p_4 &= a + b\alpha^{4(t_1 - t_0)} + c\beta^{4(t_1 - t_0)}
\end{aligned}\right\} \qquad (2)$$

Now subtract each equation, member for member, from the one below it, and for convenience let

$$\log p_1 - \log p_0 = y_0, \text{ etc.}, \quad \alpha^{t_1 - t_0} = m, \quad \beta^{t_1 - t_0} = n.$$

$$\left.\begin{aligned}
\therefore\ y_0 &= (m - 1)\, b + (n - 1)\, c \\
y_1 &= (m^2 - m)\, b + (n^2 - n)\, c \\
y_2 &= (m^3 - m^2)\, b + (n^3 - n^2)\, c \\
y_3 &= (m^4 - m^3)\, b + (n^4 - n^3)\, c
\end{aligned}\right\} \qquad (3)$$

Solving the several equations for c and equating the values,

$$\frac{y_0-(m-1)b}{n-1}=\frac{y_1-(m^2-m)b}{n^2-n}$$

$$=\frac{y_2-(m^3-m^2)b}{n^3-n^2}=\frac{y_3-(m^4-m^3)b}{n^4-n^3}. \tag{4}$$

Again solving for b and equating the values and reducing,

$$\frac{ny_0-y_1}{n-m}=\frac{ny_1-y_2}{(n-m)m}=\frac{ny_2-y_3}{(n-m)m^2}.$$

$$\therefore\ m^2ny_0-m^2y_1=mny_1-my_2=ny_2-y_3.$$

$$\therefore\ mny_0-my_1=ny_1-y_2;\ mny_1-my_2=ny_2-y_3.$$

$$\therefore\ mn=\frac{(m+n)y_1-y_2}{y_0}=\frac{(m+n)y_2-y_3}{y_1}. \tag{5}$$

$$m+n=\frac{y_1y_2-y_0y_3}{y_1^2-y_0y_2}=M. \tag{6}$$

$$mn=\frac{y_2^2-y_1y_3}{y_1^2-y_0y_2}=N. \tag{7}$$

Equations (6) and (7) enable us to calculate numerically the values of M and N from the five given values of $\log p$. Then solving for m and n,

$$m=\frac{M}{2}-\left(\frac{M^2}{4}-N\right)^{\frac{1}{2}}.$$

$$n=\frac{M}{2}+\left(\frac{M^2}{4}-N\right)^{\frac{1}{2}}.$$

Solving one of the equations (4) for b,

$$b=\frac{ny_0-y_1}{n(m-1)-(m^2-m)}=\frac{ny_0-y_1}{(m-1)(n-m)}. \tag{8}$$

Again, solving the first equation of (3) for c,

$$c=\frac{y_0-\dfrac{ny_0-y_1}{n-m}}{n-1}=\frac{y_1-my_0}{(n-1)(n-m)}. \tag{9}$$

From the first equation of (2),

$$a=\log p_0-b-c. \tag{10}$$

Finally, $$\alpha=m^{\frac{1}{t_1-t_0}}, \tag{11}$$

$$\beta=n^{\frac{1}{t_1-t_0}}. \tag{12}$$

In the *Mémoires de L'Institute de France, Tome XXI.*, Regnault gives the following data:—

Temperature Degrees Centigrade.	Pressure mm. of Mercury.
$t_0 = 100$	$p_0 = 760.00$
$t_1 = 130$	$p_1 = 2030.0$
$t_2 = 160$	$p_2 = 4651.6$
$t_3 = 190$	$p_3 = 9426.$
$t_4 = 220$	$p_4 = 17390.$

From Vega's tables,

$$\log p_0 = 2.8808135923$$
$$\log p_1 = 3.3074960379$$
$$\log p_2 = 3.6676023618$$
$$\log p_3 = 3.9743274354$$
$$\log p_4 = 4.2402995820$$

Consequently,

$$y_0 = 0.4266824456$$
$$y_1 = 0.3601063239$$
$$y_2 = 0.3067250736$$
$$y_3 = 0.2659721466$$
$$y_1 y_2 = 0.11045363870205293904$$
$$y_0 y_3 = 0.11348564597276972496$$
$$y_1^2 = 0.12967656451277171121$$
$$y_0 y_2 = 0.13087420453048799616$$
$$y_2^2 = 0.09408027077292539670$$
$$y_1 y_3 = 0.09577825197191788374$$

$$m + n = \frac{y_1 y_2 - y_0 y_3}{y_1^2 - y^0 y_2} = M = 2.5316516030404167591$$

$$mn = \frac{y_2^2 - y_1 y_3}{y_1^2 - y_0 y_3} = N = 1.4177725976711062143$$

$$M^2 = 6.4092598391771119149$$

$$\frac{M^2}{4} - N = 0.18454236212317176 44$$

$$\left(\frac{M^2}{4} - N\right)^{\frac{1}{2}} = 0.4295839407$$

$$m = \frac{M}{2} - \left(\frac{M^2}{4} - N\right)^{\frac{1}{2}} = \alpha^{t_1 - t_0} = \alpha^{30} = 0.8362418608$$

$$n = \frac{M}{2} + \left(\frac{M^2}{4} - N\right)^{\frac{1}{2}} = \beta^{t_1 - t_0} = \beta^{30} = 1.6954097422$$

$$\log \alpha^{30} = 9.9223319038-10$$
$$\log \beta^{30} = 0.2292746734$$
$$\log \alpha = 9.9974\,1106346-10$$
$$\log \beta = 0.0076424891\,13$$
$$ny_0 = 0.7234015751$$
$$(m-1)(n-m) = 0.1406957337$$
$$b = \frac{ny_0 - y_1}{(m-1)(n-m)} = -2.5821340985$$
$$my_0 = 0.3568097223$$
$$(n-1)(n-m) = 0.5974737149$$
$$c = \frac{y_1 - my_0}{(n-1)(n-m)} = 0.0055175674$$
$$a = \log p_0 - b - c = 5.4574301234$$

Collecting the quantities we have

C. For $100° - 220°$ C.

$$\log p = a - b\alpha^n + c\beta^n$$
$$n = t - 100$$
$$a = 5.4574301234$$
$$\log b = 0.4119787931$$
$$\log c = 7.7417476470-10$$
$$\log \alpha = 9.9974\,1106346-10$$
$$\log \quad = 0.0076424891\,13$$

Considering that one place of decimals is necessarily lost in the application of the formula, these values must be considered satisfactory, as shown by the following table:—

Temperature Degrees Cent.	Pressure mm. of Mercury.	Logarithms of Pressure. Vega's Tables.	By Formula.
100	760.00	2.8808135923	2.880813592
130	2030.0	3.3074960379	3.307496036
160	4651.6	3.6676023618	3.3667602359
190	9426.	3.9743274354	3.974327428
220	17390.	4.2402995820	4.240299575

From Regnault's memoires we have also:—

Temperature Degrees Centigrade.	Pressure mm. of Mercury.
$t_0 = 0$	$p_0 = 4.60$
$t_1 = 25$	$p_1 = 23.55$
$t_2 = 50$	$p_2 = 91.98$
$t_3 = 75$	$p_3 = 288.50$
$t_4 = 100$	$p_4 = 760.00$

From Vega's tables :—

$$\log p_0 = 0.6627578317$$
$$\log p_1 = 1.3719909115$$
$$\log p_2 = 1.9636934052$$
$$\log p_3 = 2.4601458175$$
$$\log p_4 = 2.8808135923$$

Consequently :—

$$y_0 = 0.7092330798$$
$$y_1 = 0.5917024937$$
$$y_2 = 0.4964524123$$
$$y_3 = 0.4206677748$$
$$y_1 y_2 = 0.293752130359$$
$$y_0 y_3 = 0.298351501494$$
$$y_1^2 = 0.350111841050$$
$$y_0 y_2 = 0.352100473350$$
$$y_2^2 = 0.246464997678$$
$$y_1 y_3 = 0.248910171368$$

$$m + n = \frac{y_1 y_2 - y_0 y_3}{y_1^2 - y_0 y_2} = M = 2.3128313535$$

$$mn = \frac{y_2^2 - y_1 y_3}{y_1^2 - y_0 y_3} = N = 1.2295755604$$

$$M^2 = 5.3491888697$$
$$N^2 = 1.3372972174$$

$$\left(\frac{M^2}{4} - N\right)^{\frac{1}{2}} = 0.3282097759$$

$$m = \frac{M}{2} - \left(\frac{M^2}{4} - N\right)^{\frac{1}{2}} = \alpha^{t_1 - t_0} = \alpha^{25} = 0.8282059009$$

$$n = \frac{M}{2} + \left(\frac{M^2}{4} - N\right)^{\frac{1}{2}} = \beta^{t_1 - t_0} = \beta^{25} = 1.4846254527$$

$$\log \alpha^{25} = 9.9181383205$$
$$\log \beta^{25} = 0.1716168981$$
$$\log \alpha = 9.996725532820 - 10$$
$$\log \beta = 0.006864675924$$
$$n y_0 = 1.052945822$$
$$(m - 1)(n - m) = 0.4612429885$$

$$b = \frac{n y_0 - y_1}{(m - 1)(n - m)} = -4.0901574574$$

$$m y_0 = 0.5873910218$$
$$(n - 1)(n - m) = 0.3181176176$$
$$c = 0.0135530749$$
$$a = \log p_0 - b - c = 4.7393622142$$

Collecting the quantities,

B. For $0° - 100°$ C.

$$\log p = a - b\,\alpha^n + c\,\beta^n$$

$$n = t$$

$$a = 4.7393622142$$

$$\log b = 0.6117400190$$

$$\log c = 8.1320378383 - 10$$

$$\log \alpha = 9.996725532820 - 10$$

$$\log \beta = 0.006864675924$$

This equation was calculated subsequently to the equation for 100° to 220° C., and the work was not carried to so many places of decimals; still the values are sufficiently accurate, as shown by the following table:—

Temperature Degrees Cent.	Pressure mm. of Mercury.	Logarithms of Pressure. Vega's Tables.	By Formula.
0	4.60	0.6627578317	0.66275783
25	23.55	1.3719909115	1.37199098
50	91.98	1.9636934052	1.96369346
75	288.50	2.4601458175	2.46014587
100	760.00	2.8808135923	2.88081365

Since the data are given in five places of significant figures, of which the last figure must be in doubt to one or two units, if not more, it appears that the work has been carried to a needless degree of refinement. The reason for carrying the work to such a degree was to make a future investigation unnecessary.

For calculation the following equations are recommended. They give six places of significant figures, of which five may be retained in the results.

Pressure of steam at Paris, French units.

$$\log p = a - b\,\alpha^n + c\,\beta^n$$

B. For $0°$ to $100°$ C.

$$n = t$$

$$a = 4.739362$$

$$\log b = 0.6117400$$

$$\log c = 8.13204 - 10$$

$$\log \alpha = 9.996725533 - 10$$

$$\log \beta = 0.0068647$$

C. For $100°$ to $220°$ C.

$$n = t - 100$$

$$a = 5.457430$$

$$\log b = 0.4119788$$

$$\log c = 7.74175 - 10$$
$$\log \alpha = 9.997411063 - 10$$
$$\log \beta = 0.0076425$$

The standard thermometer may be considered to be one having its boiling and freezing points determined under a pressure of 760 mm. of mercury at sea level and at the latitude of 45°. The equations just given may readily be transformed to give pressure at 45° latitude for temperature on the standard thermometer. The change, though small, is appreciable.

The equation

$$g = 980.6056 - 2.5028 \cos 2\lambda - 0.000003h$$

in which λ is the latitute and h is the distance above sea level in centimeters, gives for the acceleration due to gravity the following results in centimeters:—

At Paris, 48° 50′ 14″, 60 meters above the sea, $g = 980.9218$.

At 45°, sea level, $g = 980.6056$.

Consequently 760 mm. of mercury at 45° will produce a pressure equal to that of

$$760 \times \frac{980.6056}{980.9218} = 759.755 \text{ mm.}$$

of mercury at Paris. Either of the equations for steam at Paris gives for the pressure at 99° C, 759.73 mm. of mercury, and by interpolation the temperature corresponding to 759.755 mm. is 99.991° C. That is, one degree on the standard thermometer has 0.99991 of the length of the degree of a thermometer graduated at Paris.

Again, the column of mercury at 45° latitude which gives a certain pressure is $\frac{980.9218}{980.6056}$ times as high as a column of mercury at Paris giving the same pressure.

Consequently the equation for pressures of steam from 0° to 100° C. at latitude 45° becomes

$$\log p = a + \log \frac{980.9218}{980.6056} - b\alpha^{0.99991t} + c\beta^{0.99991t}$$

and the equation for pressures of steam at the same latitude from 100° to 220° becomes

$$\log p = a + \log \frac{980.9218}{980.6056} - b\alpha^{(0.99991t - 100)} + c\beta^{(0.99991t - 100)}$$

or,

$$\log p = a + \log \frac{980.9218}{980.6056} - b\alpha^{-0.009\ \ 0.99991(t-100)} + c\beta^{-0.009\ \ 0.99991t(-100)}\ \beta$$

Reducing equations B and C at Paris by this method we have the following

Pressure of steam at 45° latitude French units.

$$\log p = a - b\alpha^n + c\beta^n$$

B. For 0° to 100° C.

$$n = t$$
$$a = 4.739502$$
$$\log b = 0.6117400$$
$$\log c = 8.13204 - 10$$
$$\log \alpha = 9.996725828 - 10$$
$$\log \beta = 0.0068641$$

C. For 100° to 220° C.

$$n = t - 100$$
$$a = 5.457570$$
$$\log b = 0.4120021$$
$$\log c = 7.74168 - 10$$
$$\log \alpha = 9.997411296 - 10$$
$$\log \beta = 0.0076418$$

To transform the above equations so as to give the pressure in pounds on the square inch for temperatures on the Fahrenheit scale, the following data are required: —

Length of the meter in inches (Rogers), 39.3702.

Weight of the kilogram in pounds (Miller), 2.20462125.

Weight of one liter of mercury (Regnault), 13.5959.

One degree F $= \frac{5}{9}$ of one degree C.

The pressure of one mm. of mercury in pounds on the square inch is

$$\frac{13.5959 \times 2.204621}{39.3702^2} = k.$$

Applying this to the preceding equations,

$$\log p = a + \log k - b\,\alpha^{\frac{5}{9}n} + c\beta^{\frac{5}{9}n}$$

from which are derived the following equations, giving the pressure of saturated steam in pounds on the square inch for each degree Fahrenheit.

Pressure of steam at 45° latitude, English units.

$$\log p = a - b\alpha^n + c\beta^n$$

B. For 32° to 212° F.

$$n = t - 32$$
$$a = 3.025908$$

$$\log b = 0.6117400$$
$$\log c = 8.13204 - 10$$
$$\log \alpha = 9.99818015 - 10$$
$$\log \beta = 0.0038134$$

C. For $212° - 428°$ F.

$$n = t - 212$$
$$a = 3.743976$$
$$\log b = 0.4120021$$
$$\log c = 7.74168 - 10$$
$$\log \alpha = 9.99856183 1 - 10$$
$$\log \beta = 0.0042454$$

Owing to the difficulty of determining the density of saturated steam by direct experiment, it is customary to calculate it by the equation

$$s = \frac{r}{AT} \cdot \frac{1}{\frac{dp}{dt}} + \sigma \tag{13}$$

in which r is the latent heat of vaporization, A is the reciprocal of the mechanical equivalent of heat, T is the temperature above the absolute zero, and σ is the volume of one unit of weight of water. $\frac{dp}{dt}$ is to be determined from the equations giving p, the specific pressure.

Instead of the general equation

$$\log p = a + b\alpha^n + c\beta^n$$

we may write

$$\log_e p = \frac{1}{M} a + \frac{1}{M} b\alpha^n + \frac{1}{M} c\beta^n \tag{14}$$

in which M is the modulus of the common system of logarithms. Differentiating

$$\frac{dp}{p\,dt} = \frac{1}{M} b \log_e \alpha \cdot \alpha^n + \frac{1}{M} c \log_e \beta \cdot \beta^n \tag{15}$$

or reducing to common logarithms,

$$\frac{1}{p}\frac{dp}{dt} = \frac{1}{M^2} b \log \alpha \cdot \alpha^n + \frac{1}{M^2} c \log \beta \cdot \beta^n \tag{16}$$

or

$$\frac{1}{p}\frac{dp}{dt} = A\alpha^n + B\beta^n$$

Differential co-efficient; French units.

B. For 0° to 100° *C.*, mm. of mercury.

$$\log A = 8.8512729 - 10$$
$$\log B = 6.69305 - 10$$
$$\log \alpha = 9.996725828 - 10$$
$$\log \beta = 0.0068641$$

C. For 100° to 220° C., mm. of mercury.

$$\log A = 8.5495158 - 10$$
$$\log B = 6.34931 - 10$$
$$\log \alpha = 9.997411296 - 10$$
$$\log \beta = 0.0076418$$

Differential co-efficient, English units.

B. For 32° to 212° F., pounds on the square inch.

$$\log A = 8.5960005 - 10$$
$$\log B = 6.43778 - 10$$
$$\log \alpha = 9.99818101 5 - 10$$
$$\log \beta = 0.0038134$$

C. For 212° to 428° F., pounds on the square inch.

$$\log A = 8.2942434 - 10$$
$$\log B = 6.09403 - 10$$
$$\log \alpha = 9.998561831 - 10$$
$$\log \beta = 0.0042454$$

It is to be remarked that $\frac{dp}{dt}$ may be found approximately by dividing a small difference of pressures by the corresponding difference of temperatures; that is, by calculating $\frac{\Delta p.}{\Delta t}$ With a table for even degrees of temperature, the differential co-efficient for a given temperature is found by dividing the difference of the pressures corresponding to the next higher and the next lower degrees by two.

Each of the equations for the pressure of steam in English units gives 14.6967 pounds on the square inch at 212° F., as should be the case. But equation B. for the differential co-efficient gives at 212° F.,

$$\frac{1}{p}\frac{dp}{dt} = 0.0198912,$$

while equation C. gives, at the same temperature,

$$\frac{1}{p}\frac{dp}{dt} = 0.0198141.$$

This discrepancy is due to the fact that the direction of the curves represented by the equations is not the same at their point of meeting, and appears to be inevitable. A similar uncertainty affects all the calculations depending on the differential co-efficient.

The mean of the two values above is

$$\frac{1}{p}\frac{dp}{dt} = 0.01985,$$

which differs from either extreme by about one in five hundred. In equation (13), r, the latent heat of vaporization deduced from Regnault's experimental work is uncertain, to the extent of one unit in 600, so that the error from the use of the differential co-efficient in that equation is not larger than the errors from other sources. Since the errors in the experimental determinations of the density of saturated vapor by Tate and Fairbairn amount to two or three units in one hundred, the calculation by aid of equation (13) are to be preferred.

Vol. I. MAY, 1888. No. 4.

TECHNOLOGY QUARTERLY

CONTENTS

The Beginning of the Massachusetts Institute of Technology,	*James P. Munroe, S.B.*	285
*Discussion of the Precision of Measurements (concluded)	*Silas W. Holman, S.B.*	298
Friction and Lubrication	*W. O. Webber*	324
Notes on Assaying of Lead, Silver, and Gold. II.	*Frederick W. Clark, S.B.*	330
Preparation and Action of Alizarine Assistant	*Charles B. Kendall, S.B.*	345
Ruling Gradient	*Eliot Holbrook, S.B.*	351
Notes on the Engineering Laboratories of the Massachusetts Institute of Technology	*Gaetano Lanza, S.B., C.E.*	356
Note on a Funnel for Filtering Carbon	*Thomas M. Drown, M.D.*	374
Heating and Ventilation (Notes)	*S. H. Woodbridge, A.M.*	376
Notes on the Structure of the Quills of the Porcupine	*Edw. G. Gardiner, Ph.D.*	392
Quartzites and Siliceous Concretions	*W. O. Crosby, S.B.*	397
Mineralogical Notes: —		
Vesuvianite from Newbury, Mass.	*W. O. Crosby and James T. Greeley*	407
Gahnite, or Zinc-Spinel, from Rowe, Mass.	*W. O. Crosby and Charles L. Brown*	408
The Proper Method of Comparing the Cost of Chilled-Iron and Steel-Tired Car Wheels	*George F. Swain, S.B.*	409
Pressure of Saturated Steam	*C. H. Peabody, S.B.*	416

* Copyrighted, 1888, by S. W. Holman.

MASSACHUSETTS INSTITUTE TECHNOLOGY.

BOSTON.

Entered as second-class mail matter at the Boston Post-office.

AS DIRECT IMPORTERS WE GUARANTEE THE LOWEST PRICES.

Microscopes.

The only House in the country carrying in stock Microscopes of the leading manufacturers of Europe—

Zeiss, Hartnack, Nachet, Reichert, Leitz.

MICROSCOPIC ACCESSORIES.

German and English, Chance and Hartigs.

CHEMICAL AND PHYSICAL APPARATUS.

The best quality only.

Kavalier, Gerhardt, Kuchler, Geissler, Buhler, Wiesnegg.

BERLIN PORCELAIN, HAMMERED PLATINUM.

SCHLEICHER & SCHULL'S FILTER-PAPER.

MICROTOMES:

Jung, Heidelberg, Becker, Gottingen.

BALANCES:

Westphal, Becker.

THE EDUCATIONAL SUPPLY COMPANY,

6 HAMILTON PLACE, BOSTON.

Correspondence Solicited.

HENRY R. WORTHINGTON,

STEAM PUMPING MACHINERY

OF EVERY DESCRIPTION.

BOILER FEED PUMPS. TANK PUMPS. PRESSURE PUMP.

FIRE PUMPS. HYDRAULIC ELEVATOR PUMPS, ETC., ETC.

INDEPENDENT CONDENSERS. WATER METERS.

Water Works, Pumping Engines. Highest Duties Guaranteed.

BOSTON OFFICE, 70 KILBY STREET.

NEW YORK, BOSTON, PHILADELPHIA, CHICAGO, ST. LOUIS, SAN FRANCISCO

Send for Illustrated Catalogue.

TECHNOLOGY QUARTERLY.

Board of Editors:

WM. E. MOTT, '88, Editor-in-Chief.
WM. L. HARRIS, '88, Secretary.
GEORGE E. CLAFLIN, '88, Treasurer.
ARTHUR T. BRADLEE, '88, Business Manager.
JAMES P. GILBERT, '89, Advertising Agent.

HAROLD O. BINNEY, '88.
HORACE P. EDGETT, '89.
ARTHUR V. EDWARDS, '89.
FRANCIS R. HART, '89.
WINSLOW BLANCHARD, '88.
WILLIAM W. LEWIS, '89.
FRED W. RANNO, '89.
WM. B THURBER, '89.

Introductory.

THE TECHNOLOGY QUARTERLY is published by a Board of Editors chosen from the Senior and Junior classes of the Massachusetts Institute of Technology, representing, so far as possible, all the departments of the Institute.

A large amount of original work is done in the Institute every year by the advanced students which lacks a suitable channel of publication. It is thought by the editors that the QUARTERLY will be an acceptable journal if it contains nothing more than the results of the original investigations made in the chemical, physical, mining, mechanical, and biological laboratories, and also in the departments of civil engineering and architecture. But it is further expected that the alumni of the Institute will be glad of this medium for recording their investigations and the results of their practical work.

The QUARTERLY will be issued four times during the school-year—October, December, February, and April.

The subscription price is two dollars a year, in advance.

ALBERT L. RUSSELL,

MANUFACTURER OF AND DEALER IN

Telegraph and Electrical Instruments,

GALVANIC BATTERIES,

Line Wire, Insulated Magnet Wire, Fine Instruments for Electric Testing, etc.

SUCCESSOR TO CHARLES WILLIAMS, JR.

109 COURT STREET - - BOSTON, MASS.

MASSACHUSETTS HEEL MACHINE CO.,

Office, 148 High Street, Boston.

BOOT AND SHOE HEELS BY PATENT PROCESS.

Correspondence Solicited.

JOHN P. POWERS, SUPT.

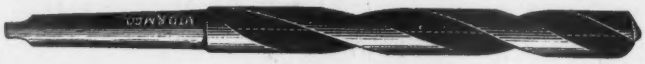
FACTORIES: { Portland, Me. / Boston, Mass.

Morse Twist Drill and Machine Company,

NEW BEDFORD, MASS.,

Manufacturers of

Morse Pat. Straight-Lip Increase Twist Drills.



Beach's Patent Self-Centering Chucks.

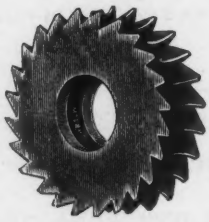
SOCKETS.

Bit-Stock Drills.

Machine Bits for Wood.

Standard Gauges.

Milling



Cutters.

Taper, Solid and Shell Reamers.

Taps and Dies.

Screw Plates.

Tap Wrenches.

Special Tools and Drill Grinding Machines.

HOLMES & BLANCHARD

MANUFACTURERS OF

French Buhr Millstones,

IMPROVED PORTABLE MILLS,

MILL-GEARING of ALL DESCRIPTIONS

And all Machinery for Grinding Corn, Wheat, Salt, Coal, etc., etc.

BOLTING-CLOTH, MILL-PICKS, AND ALL MILLERS' SUPPLIES.

Machinery used in Manufacturing and Grinding ***Paints and Colors*** in Oil, Japan, or Water.

Bone Mills, and all Machinery for Manufacturing and Mixing FERTILIZERS.

Chocolate Mills, Hot Kettles, Melangeurs, Rolls, Cocoa-Crackers, etc., etc.

Platform Elevators, for Stores and Warehouses.

New England Agents for WATERTOWN STEAM-ENGINE CO.'S AUTOMATIC and SLIDE-VALVE

ENGINES

PORTABLE AND DAIRY ENGINES AND BOILERS.

Wood Cogged Gears in great variety. Old Gears Recogged.

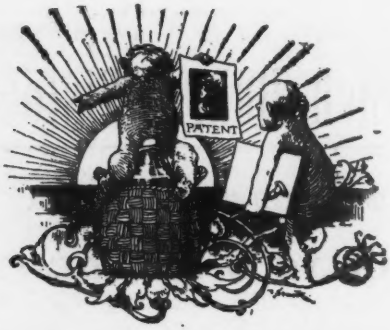
Shafting, Pulleys, and Hangers in large stock, always on hand, ready for immediate delivery.

Transmission of Power by Wire Rope arranged, and all parts furnished and set.

MILLWRIGHT-WORK OF ALL KINDS.

37 and 39 Charlestown Street, BOSTON.

Cuts for College Publications!



VIEWS OF COLLEGE BUILDINGS, PORTRAITS OF THE FACULTY, and ILLUSTRATIONS FOR COLLEGE JOURNALS.

Class Pictures and Albums a Specialty.

Copies of Architectural, Mechanical, Scientific, and other Drawings, Maps, Plans, and Diagrams. Artistic Programmes, Invitations, Menu Cards, Dance Orders, etc., etc.

A new line of choice and attractive

Heliotype Engravings

Now ready, printed on heavy plate paper, 22 x 28 inches, with Engraved Title and India Tint. ***Price, 75 Cents each.*** Sent postpaid, securely wrapped in roll, on receipt of One Dollar. An Illustrated Catalogue sent on receipt of stamp.

HELIOTYPE PRINTING CO.,

211 Tremont St., Boston.

FROST & ADAMS,

IMPORTERS, WHOLESALE AND RETAIL DEALERS IN

ARTISTS' MATERIALS

—OF EVERY DESCRIPTION.—

DECORATIVE ART GOODS OF ALL KINDS.

Handbooks of Instruction on all Art Subjects.

Supplies for Oil Color, Water Color, China, Lustra, and Tapestry Painting. Studies for all Branches of Art Work.

Mathematical Instruments, Drawing Paper, and T Squares.

ARCHITECTS' AND ENGINEERS' SUPPLIES IN GENERAL.

37 CORNHILL, BOSTON, MASS.

Catalogues FREE on application. Mail orders receive prompt attention.

F. S. FROST. H. A. LAWRENCE.

SAML. CABOT,

MANUFACTURING CHEMIST.

COAL TAR PRODUCTS,

Creosote Stains,
Mortar Colors,
Lampblack,
And other Specialties.

OFFICE, 70 KILBY STREET,

FACTORIES { *Chelsea, Mass.* / *Buffalo, Pa.* } **BOSTON, MASS.**

PRANG'S ARTISTS' MATERIALS

7 PARK STREET, BOSTON.

We carry a full line of first-class Artists' Material Goods, comprising

OIL COLORS, WATER COLORS,

CANVAS, BRUSHES, CRAYONS,

EASELS, PALETTES, INSTRUMENTS,

As well as Materials used in Decorative Work. Particular attention is invited to our

Materials for Water-Color Painting,

COMPRISING A LINE OF

PRANG'S WATER COLORS, PRANG'S BRUSHES, PRANG'S PREPARED BLOCKS OF WHATMAN'S PAPERS.

☞ For full particulars as to goods and prices, send for Catalogue, which is mailed free on application

THE PRANG EDUCATIONAL CO.,

7 PARK STREET, BOSTON.

BEST WORK, FULL COUNT, LOWEST PRICES, PROMPT DELIVERY.

FRANK WOOD,

Printer,

NO. 352 WASHINGTON STREET,

BOSTON.

SPECIAL ATTENTION PAID TO WORK FOR SCHOOLS AND COLLEGES.

LOWEST PRICES ON

DRAFTING INSTRUMENTS,

COLORS,

Drawing-Papers,
Blue Process Papers,
T Squares Scales,
Curves Triangles

AND ALL KINDS OF

Architects' and Engineers' Supplies, and Artists' Materials,

AT

WADSWORTH, HOWLAND & CO.'S,

82 and 84 Washington St., and 46 Friend St.,

BOSTON, MASS.,

263 and 265 Wabash Avenue, Chicago, Ill.

FACTORIES: { *Portland St., Boston.* / *Clinton St., Chicago*

SEND FOR CATALOGUE.

EVERY STUDENT SHOULD READ

The Electrical World!

A Handsomely and Copiously Illustrated 28-page Weekly Review of

Current Progress in Electricity and its Practical Application.

ISSUED EVERY SATURDAY.

W. H. JOHNSTON, Editor and Publisher.

T. COMMERFORD MARTIN, and JOSEPH WETZLER, Associate Editors.
CLARENCE E. STUMP, Business Manager.

Publication Offices, 168-177 Potter Building, New York.

SUBSCRIPTION, IN ADVANCE, ONE YEAR, THREE DOLLARS.

Postage in the United States and Canada is always prepaid by the Publisher.

THE ELECTRICAL WORLD

Is the PIONEER WEEKLY ELECTRICAL JOURNAL OF AMERICA, and has well maintained its lead. It HAS *the largest circulation of any periodical in the world devoted to electricity*, and is noted for its ABILITY, ENTERPRISE, INDEPENDENCE, AND HONESTY.

Avoiding abstruse technicalities, **The Electrical World** seeks to keep its readers informed of every event of importance, every new discovery, invention, application and theory in which Electricity plays a part. No one who desires to keep abreast of the wonderful activity in electrical discovery and invention that characterizes our times, can afford to be without it.

Correspondence, news items, views and opinions on all topics within the province of this journal are cordially invited from any part of the world.

THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

BOYLSTON ST., BOSTON, MASS.

FRANCIS A. WALKER, President.

THE School of Industrial Science aims to give thorough instruction in *Civil*, *Mechanical*, *Chemical*, (established this year,) *Mining*, *and Electrical Engineering*, *in Chemistry*, *Architecture*, *Physics*, *and Natural History*. It offers, also, a course in *Biology*, preparatory to the study of *Medicine*, and a *General Course* based upon scientific study and experiment, but admitting of more instruction in language, literature, and political science than is possible in the other courses.

To be admitted to the School, the applicant must have attained the age of seventeen years, and must pass examinations in arithmetic, algebra, plane geometry, English grammar and rhetoric, modern history and literature, French (or German) and geography. A definite division of these examinations between two successive years is allowed.

Examinations will be held on May 31st and June 1st, in Boston, New York, Philadelphia, Chicago, Washington, San Francisco, St. Paul, and Pittsburgh, and probably in Montreal, St. Louis, Cincinnati, Nashville, and Atlanta; and on Sept. 18th and 19th, in Boston only.

Instruction is given by means of lectures and recitations, supplemented by appropriate work in the laboratory, drawing-room, or field. To this end, extensive laboratories of chemistry, physics, biology, mining, mechanical engineering, applied mechanics and the mechanic arts have been thoroughly equipped, and unusual opportunities for field-work and for the examination of existing structures and industries have been secured.

The work of instruction is in charge of thirteen professors, fifteen associate and assistant professors, and forty-seven instructors and assistants. It is sought to give, so far as is practicable, personal instruction to small sections, rather than lectures to large bodies of students.

The regular courses are of four years' duration, and lead to the degree of Bachelor of Science. Shorter special courses are offered to those properly prepared, and advanced degrees of Master or Doctor of Science and of Doctor of Philosophy are given for study subsequent to graduation.

The tuition fee, including everything except breakage in the chemical laboratory, is $200 a year. In addition, $25 or $30 per year are required for books and drawing-materials.

For catalogues and information, address

JAMES P. MUNROE, *Secretary.*

RUBBER BELTING, PACKING & HOSE.

Oldest and Largest Manufacturers in the United States of

VULCANIZED RUBBER FABRICS

For Mechanical Purposes.

STEAM HOSE

A SPECIALTY.

Rubber Mats,
Rubber Matting
and Stair Treads.

NEW YORK BELTING & PACKING CO.,

15 Park Row, New York.

HALL RUBBER CO., BOSTON, Agents.

LIDGERWOOD MANUFACT'G CO.,

MANUFACTURERS OF IMPROVED

Hoisting Engines and Boilers

FOR RAILROAD PURPOSES,

Excavating and Pile Driving.

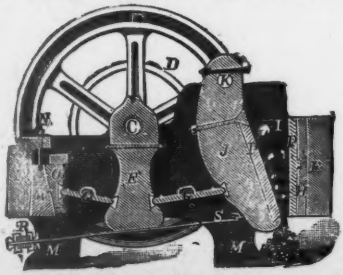
OVER 4000 ENGINES IN USE.

300 STYLES AND SIZES.

J. H. Houghton, Agt., Boston.

WAREHOUSE, 96 LIBERTY ST., N. Y.

IMPROVED ROCK-CRUSHERS.



THE BLAKE STYLE.

For crushing all kinds of hard, brittle substances.

Quartz, Emery & Corundum,

Also TRAP ROCK for

Road Ballast & Concrete.

Over 40 Gold and Silver Medals.

Mr. S. L. MARSDEN, who for the past twenty years has been connected with the manufacture of the "Blake Crusher," New Haven, superintends the construction of this machine.

FARREL FOUNDRY & MACHINE CO.,

ANSONIA, CONN.

COPELAND & BACON, Gen'l Agents, 85 Liberty St., N. Y., 309 Arch St., Philadelphia.

B. F. STURTEVANT.

Patentee and Sole Manufacturer of the

Sturtevant Blower and Exhaust Fan.

For Cupola Furnaces, Forges, Steam Boilers, Heating Furnaces, Drying Wool, Cotton, Etc., and for Purposes of Ventilation.

For Carrying off Shavings and Saw-dust, Dust from Sand and Emery Wheels, Removing Gas, Smoke, and all Noxious Fumes.

Salesroom, 115 Purchase St., Office and Works at Jamaica Plain, BOSTON, MASS.

Sprague Electric Railway and Motor Co.

STATIONARY MOTORS. **MOTORS FOR RAILWAY PURPOSES.**

The standard types for stationary work range from 1-2 to 25-horsepower, of which the power quoted is in every case guaranteed. In the larger sizes the efficiency exceeds 90 per cent.

☞ Catalogue of Stationary Motors, and Circular giving details and advantages of Sprague Railway System, sent on application.

NEW YORK OFFICE, 16 BROAD STREET.

BOSTON OFFICE, 55 OLIVER STREET.

A. J. WILKINSON & CO.,

Importers, Manufacturers, and Dealers in

Hardware and Fine Tools,

OF EVERY DESCRIPTION.

Lathes, Scroll Saws, and Machinists' and Manufacturers' Supplies.

180 to 188 Washington, & 19 to 25 Devonshire Sts.,

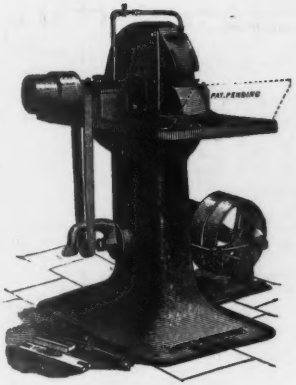
BETWEEN STATE STREET AND DOCK SQUARE,

BOSTON.

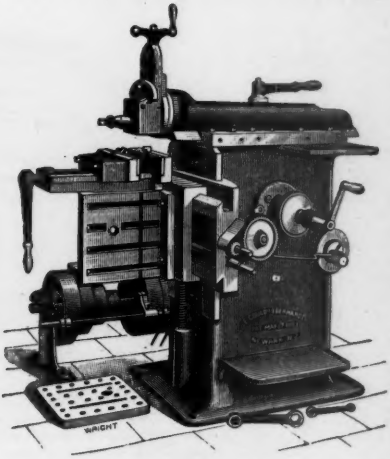
GOULD & EBERHARDT,

Near Market Street Depot Penn. R. R., Newark, N. J.

Makers of

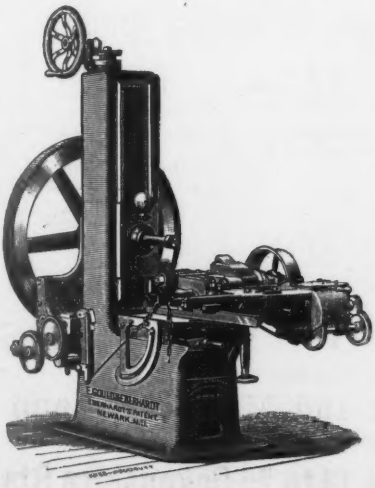


Eberhardt's Pat. New
TOOL-GRINDER.
3 Sizes.

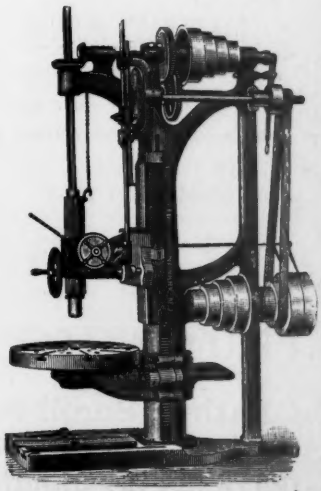


PAT. SHAPERS.
Over 1000 in use
Sizes, 10, 15, 20, 25, 30 Inch

MODERN AUTOMATIC MACHINERY.



Eberhardt's Pat. Entirely
AUTOMATIC GEAR-CUTTER.
Sizes, 18, 25, 36, 50, 60 84 Inch

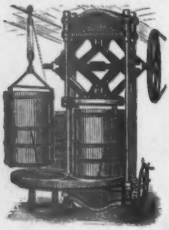


Eberhardt's Pat.
AUTOMATIC DRILL-PRESS.
Sizes, 24, 30, 36, 42 Inch and Upward.

G. H. BUSHNELL & CO.,

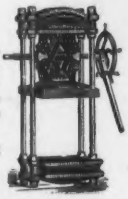
WORCESTER, MASS., U. S. A.

MANUFACTURERS OF PATENT KNUCKLE-JOINT PRESSES.



For Hand and Power, and for a variety of uses, such as

Cotton-Mills, Woolen-Mills, Paper-Mills, Wood-Pulp Mills, Dye Works, Bleacheries, Electrotypers, Book-Binders, Printers, Tanners, Veneer, Wax, Curriers, Belting, Cotton, Rags, Oleomargerine, Scrap, Herbs, Tinctures, Drugs, Wine, Cider, Parafine, Cotton-Seed, Linseed, Castor, Fish, and Lard Oils.



Correspondence solicited, especially from parties requiring Presses for new or difficult work.

Illustrated Catalogues Sent on Application.

EMIL GREINER,

MANUFACTURER AND IMPORTER OF

Chemical, Physical and Electrical Glass Apparatus,

No. 79 NASSAU STREET,

Between Fulton and John Sts., ***NEW YORK.***

SOLE MANUFACTURER OF GEISSLER & SPRENGEL'S AIR PUMPS.

Apparatus and parts of Apparatus furnished and repaired. Any Glass Apparatus according to description.

CROSBY STEAM GAGE AND VALVE CO.,

VALVE.

MANUFACTURERS OF THE

Crosby Improved Steam Gage.

Crosby Pop Safety-Valve.

Crosby Water-Relief Valve.

Crosby Steam-Engine Indicator.

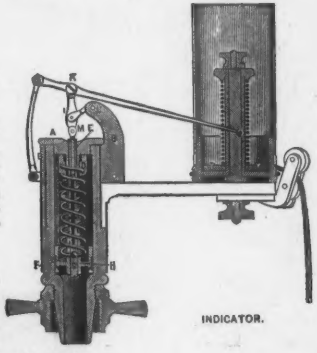
Also, Bourdon Pressure and Vacuum Gages. Hydraulic, Compound, Combination, Test, Ammonia, and all other Gages. Revolution Counters, Marine Clocks, Test Pumps, Etc., Etc. **Victory Steam-Cylinder Lubricator.**

Single-Bell Chime Whistle.

CHIME.

IMPORTERS OF

Amsler's Polar Planimeter.



INDICATOR.

Importers and proprietors of

"INVINCIBLE" GLASS TUBES.

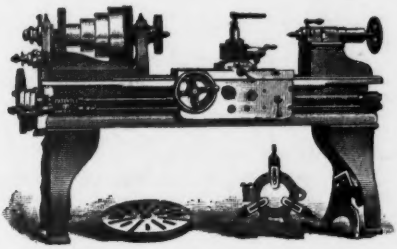
SOLE UNITED STATES AGENTS FOR

Guilbert-Martin's Patent **"RED-REFLECTING"** *Glass Tubes.*

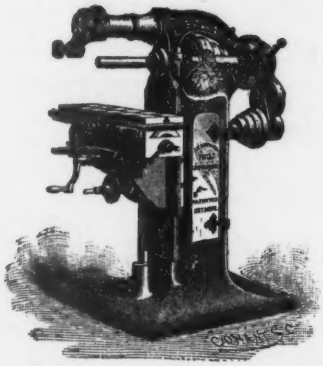
Dealers in all instruments incidental to the use of steam and other fluids.

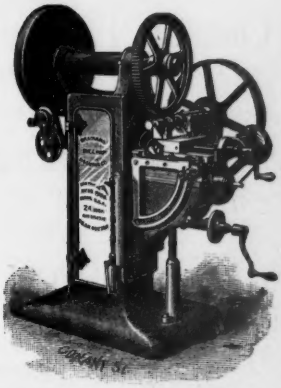
95 and 97 OLIVER ST., BOSTON.

HILL, CLARKE & CO.,

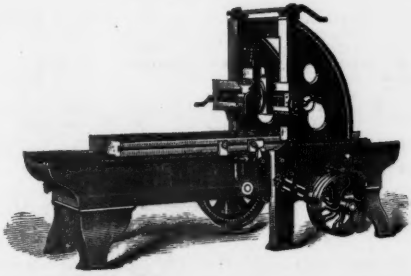


Iron Working Machine Tools,





Lathes, Planers, Drilling and Milling Machines, Etc., Etc.



156 OLIVER ST., COR. PURCHASE,

BOSTON, MASS.

Horsford's

ACID PHOSPHATE,

—FOR—

Dyspepsia, Mental and Physical Exhaustion, Nervousness, Diminished Vitality, Etc.

Prepared according to the directions of Prof. E. N. Horsford, of Cambridge.

A preparation of the phosphates of lime, magnesia, potash and iron with phosphoric acid in such form as to be readily assimilated by the system.
Universally recommended and prescribed by physicians of all schools.
Its action will harmonize with such stimulants as are necessary to take.
It is the best tonic known, furnishing sustenance to both brain and body.
It makes a delicious drink with water and sugar only.

AS A BRAIN AND NERVE TONIC.

DR. E. W. ROBERTSON, Cleveland, O., says: "From my experience, can cordially recommend it as a brain and nerve tonic, especially in nervous debility, nervous dyspepsia, etc., etc."

FOR WAKEFULNESS.

DR. WILLIAM P. CLOTHIER, Buffalo, N. Y., says: "I prescribed it for a Catholic priest, who was a hard student, for wakefulness, extreme nervousness, etc., and he reports it has been of great benefit to him.

IN NERVOUS DEBILITY.

DR. EDWIN F. VOSE, Portland, Me., says: "I have prescribed it for many of the various forms of nervous debility, and it has never failed to do good."

FOR THE ILL EFFECTS OF TOBACCO.

DR. C. A. FERNALD, Boston, says: "I have used it in cases of impaired nerve function with beneficial results, especially in cases where the system is affected by the toxic action of tobacco."

Invigorating, Strengthening, Healthful, Refreshing.

Prices reasonable. Pamphlet giving further particulars mailed free.

Manufactured by the

RUMFORD CHEMICAL WORKS,

Beware of Imitations. PROVIDENCE, R. I.

SCIENTIFIC BOOKS.

WORKS ON Architecture, Carpentry, Building, Astronomy, Meteorology, Navigation, Brewing, Distilling, Chemical and Physical Sciences, Coal, Coal Oil, Gas, Drawing, Painting, Photography, Electricity and its Applications, Engineering, Machinery, Mechanics, Geology, Mineralogy, Metallurgy, Mining, Hydraulics, Hydrostatics, Sanitary Engineering, Iron and Steel, Mathematics, Ship Building, Etc., Etc.

A large and complete assortment, both Foreign and American, for sale by

D. VAN NOSTRAND, Publisher and Importer,

23 Murray Street, NEW YORK.

ESTABLISHED 1867.

PARTRICK & CARTER,

Manufacturers of and Dealers in Every Description of

ELECTRICAL SUPPLIES

For the Telegraph, Telephone, Electric Light, etc.

Sole proprietors of the **PATENT NEEDLE ANNUNCIATOR,** Annunciators, Burglar Alarms, Electric Bells, Batteries, Wire, etc.

FRANKLIN S. CARTER.
CHAS. M. WILKINS.
E. WARD WILKINS.

No. 114 South Second Street, PHILADELPHIA, Pa.

PLATINUM

For Scientific and Mechanical Purposes.

IMPORTED AND FOR SALE BY

The S. S. White Dental Manufacturing Co.,

PHILADELPHIA—Chestnut St., cor. 12th.

NEW YORK—767 and 769 Broadway.

BOSTON—160 Tremont Street.

CHICAGO—14 and 16 E. Madison Street.

LEONARD & ELLIS,

TRADE MARK
VALVOLINE

Sole Manufacturers of

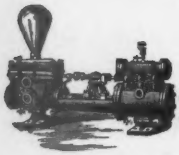
VALVOLINE • LUBRICATING • OILS.

WILLIAM JAMES GOULDING, Manager,

149 BROAD ST., BOSTON, MASS.

GEO. F. BLAKE MFG. CO.

BUILDERS OF



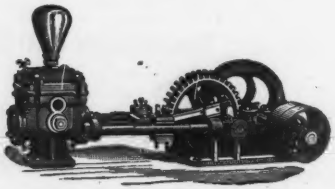
ALL KINDS OF

STEAM AND POWER

PUMPING MACHINERY,

Large and Small, for Every Kind of Service.

SINGLE OR DUPLEX, STEAM OR POWER.



POWER PUMP.

More than 20,000 in use. A Full Line Kept Constantly in Stock at our

NEW AND COMMODIOUS QUARTERS,

111 Federal Street, Boston, Mass.

NEW YORK WAREHOUSE, 95 AND 97 LIBERTY STREET.

SEND FOR CATALOGUE.

MANNING, MAXWELL & MOORE,

Manufacturers of and Dealers in all kinds of

Railway AND Machinists' Tools AND Supplies

We carry in Stock the **Largest Line of First Class Machine Tools** in the City, and a complete line of Small Tools and Machine Shop Supplies.

Salesrooms: 111 and 113 Liberty St., NEW YORK CITY.

CHAS. A. MOORE, Pres. M. LUSCOMB, Treas. GEO. W. RICHARDSON, Supt.

The Consolidated Safety Valve Company.

CAPITAL, $100,000.

Sole Manufacturers of the

Only Solid Nickel Seated Safety Valve

FOR MARINE AND STATIONARY BOILERS.

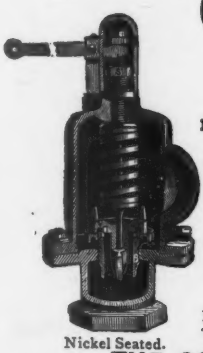
Approved by U. S. Board Supervising Inspectors. Adopted by U. S. Navy, and furnished to all the Steel Cruisers.

MADE SPECIALLY TO COMPLY WITH RECENT REQUIREMENTS OF U. S. STEAMBOAT INSPECTORS.

Angle of Seat 45°, and allowed 50% Higher Rating than Government Lever Valve.

The only Safety Valve made with

Richardson's Patent Adjustable Screw Ring.



Nickel Seated.

Yacht Valve.

Send for Illustrated Catalogue.

We are prepared to furnish the BEST SAFETY VALVE MADE, and at very low prices, when QUALITY and CAPACITY are considered. Address,

THE CONSOLIDATED SAFETY VALVE CO.

SALESROOM, 111 Liberty St., New York. WORKS, Bridgeport, Conn.

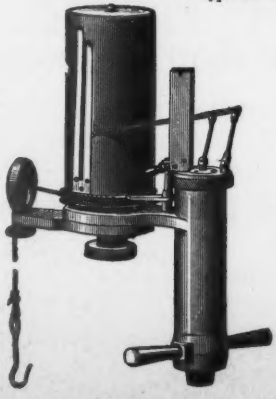
E. L. MAXWELL, Pres. C. A. MOORE, Vice-Pres. H. S. MANNING, Treas. M. LUSCOMB, Sec.

THE ASHCROFT MFG. COMPANY,

Sole Manufacturers of

THE TABOR STEAM-ENGINE INDICATOR,

Approved and Adopted by the U. S. Government.



ENGINEERING OFFICE OF CHAS. E. EMERY,
23 Cortlandt St., N. Y., Sept. 8, 1887.

THE ASHCROFT MFG. CO., 111 Liberty St., N. Y.

Gentlemen: Responding to your request, I would state that I have purchased for myself and others several Tabor Indicators, and I cheerfully bear testimony to the *excellent workmanship upon them*, to the *correctness of the principles involved*, and to the *uniform reliability* and *thorough adaptation* of the instruments for taking accurate indicator diagrams at *either high* or *low speeds*. Very truly yours,

CHAS. E. EMERY.

Also STEAM AND VACUUM GAUGES,

With Patent Seamless Drawn Tube.

Steam Traps, Packer Ratchet Drills, Stanwood Cutters, Marine Clocks, Engine Revolution Counters, Test Gauges, Oil Cups, Test Pumps, Locomotive Spring Balances, Steam Whistles, Salinometers, and all Instruments for Measuring Steam, Air, Gas, or Water.

OFFICE AND SALESROOM,

111 Liberty St., New York.

FACTORY, BRIDGEPORT, Conn.

Address all letters to P. O. BOX, 3754, N. Y.

W. H. GALLISON, BOSTON, - - EASTERN AGENT.

RICHARDS & CO.,

CHEMICAL AND PHYSICAL APPARATUS,

24 WHITEHALL STREET,

NEW YORK.

—— ESTABLISHED 1842. ——

First Premium at Franklin Institute, 1845.
First Premium at Centennial International Exhibition, 1876.

J. BISHOP & CO.

Sugartown, Chester Co., Penn.

Refiners and Melters of Platinum.

MANUFACTURERS OF

CRUCIBLES, EVAPORATING DISHES, IGNITION TUBES, AND ALL ARTICLES MADE FROM PLATINUM, USED BY ANALYTICAL CHEMISTS.

All Work HAMMERED, and WARRANTED Equal to any European Work Made.

Old Platinum bought or taken in exchange. Scrap melted at the shortest notice. Crucibles and Dishes, etc., repaired promptly. All articles sent by Adams Express, directed to ***J. BISHOP & CO., Malvern Station, P. R. R.,*** will meet with prompt attention.

Circulars Sent Free on Application.

Business Established 1851. *Incorporated 1854.*

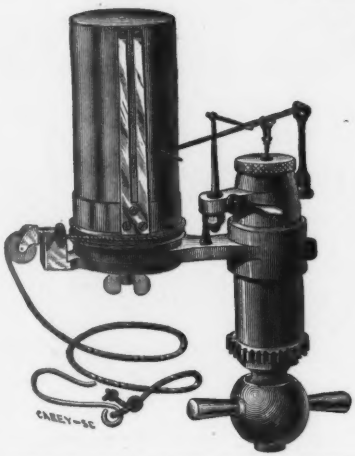
(ORIGINAL STEAM GAUGE CO.)

J. C. BLAISDELL, Pres. E. BURT PHILLIPS, Treas. H. K. MOORE, Supt.

American Steam Gauge Co.,

36 CHARDON ST., BOSTON, MASS.

Sole Manufacturers of the



Thompson Improved Indicator

2,500 IN USE.

Adopted by the U. S. Navy for use on all the Government Cruisers and Gunboats to be built.

Amsler's Polar Planimeter

—— AND ——

The Pantograph.

Also, sole manufacturers of the

+ Bourdon Steam Gauge, +

With Lane's Improvement.

Clocks, Counters, Pyrometers, Hydrometers, Salinometers, and all Instruments incidental to the use of Steam.

SEND FOR ILLUSTRATED CATALOGUE (G.)

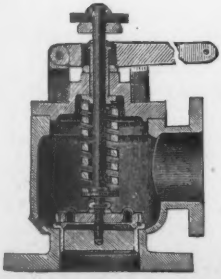
American Pop Safety Valve.

The only Automatic Adjusting Safety Valve ever produced

—— FOR ——

Locomotive, Stationary, Marine, and Portable

+ BOILERS. +



It does not infringe on the patents of any other Valve made.

We guarantee all parties buying or using them protection against all suits.

Accepted for application to all marine boilers by the Board of Supervising Inspectors of Steam Vessels, and approved by the Secretary of the Treasury at Washington, D. C., 1885.

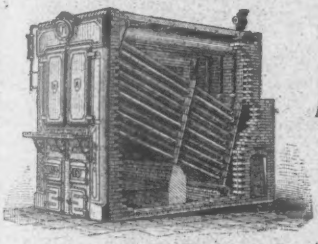
Approved, and its adoption recommended on United States Naval Steamships, April 15, 1885, by United States Naval Board of Examiners.

AMERICAN STEAM GAUGE COMPANY,

36 Chardon St., Boston, Mass.

Send for Price-List (G).

Root's New Water Tube Steam-Boiler.



SAFE, ECONOMICAL, DURABLE.

Abendroth & Root Manufacturing Co.,

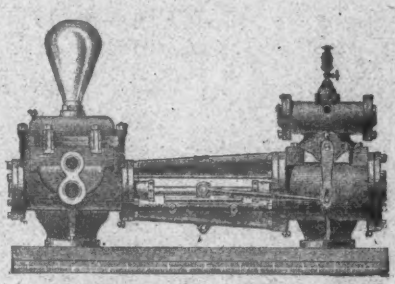
28 CLIFF ST., NEW YORK.

CHAS. E. ASHCROFT, Agent,

Mason Building, Boston.

THE M. T. DAVIDSON STEAM-PUMP.

Simple, EFFICIENT, Reliable, FOR ALL PURPOSES AND DUTIES.



MADE IN ALL SIZES, WHETHER SINGLE OR DUPLEX. ALSO COMPOUND Pumping ENGINES.

DAVIDSON STEAM-PUMP CO., 77 LIBERTY ST., NEW YORK.

Branch Office, 51 Oliver Street, Boston, Mass.

BOILER and PIPE COVERINGS.

ABSOLUTELY FIRE PROOF, Light and Cheap. EASY TO APPLY.

ASBESTOS

MINERS and MANUFACTURERS, BRAIDED PACKING, MILL BOARD, SHEATHING and SPECIALTIES.

CHALMERS-SPENCE CO., Foot of 8th St., New York.

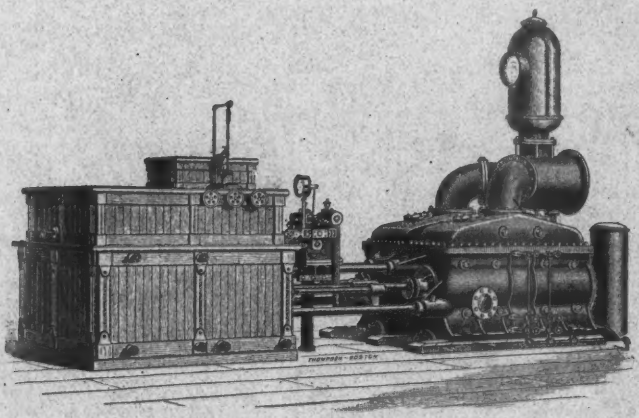
ALBERT DUTTON, Agt., 19 PEARL ST., BOSTON.

"THE DEANE"

STEAM AND POWER

PUMPS

OF EVERY VARIETY AND FOR ALL DUTIES.



MANUFACTURED BY

THE DEANE STEAM PUMP COMPANY,

HOLYOKE, MASS.

NEW YORK. BOSTON. CHICAGO. PHILADELPHIA. ST. LOUIS.

Boston Office and Warerooms, 54 Oliver St.

SEND FOR NEW ILLUSTRATED CATALOGUE.